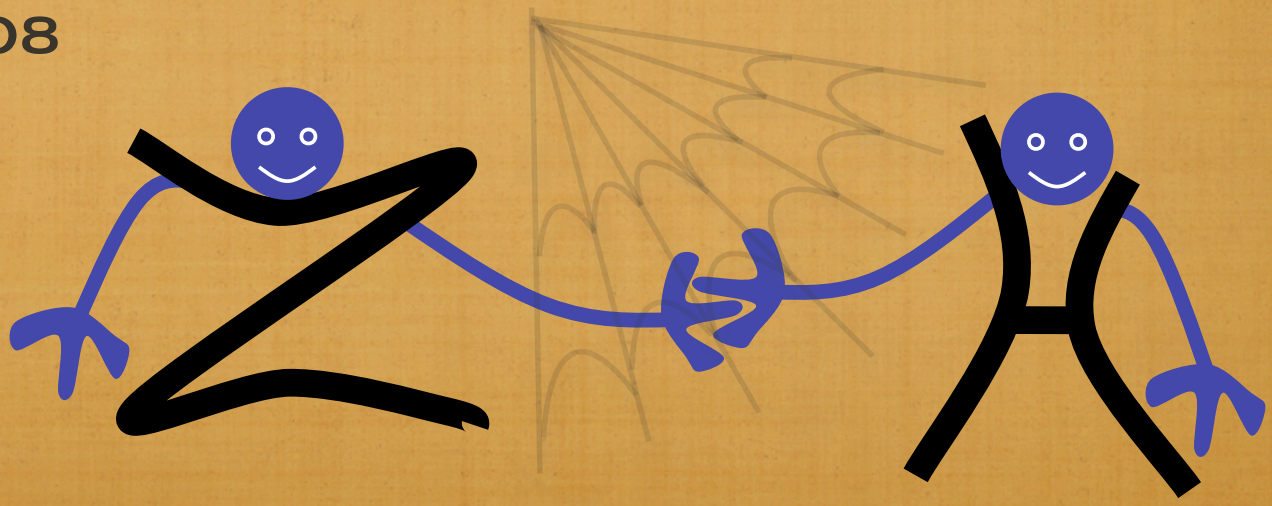
The Bad, and the Ugly : Higgs searches make good

CDF searches for standard model Higgs bosons produced with Z bosons

Ben Kilminster
Ohio State University

Users' Meeting
June 5th, 2008



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The experimental problem

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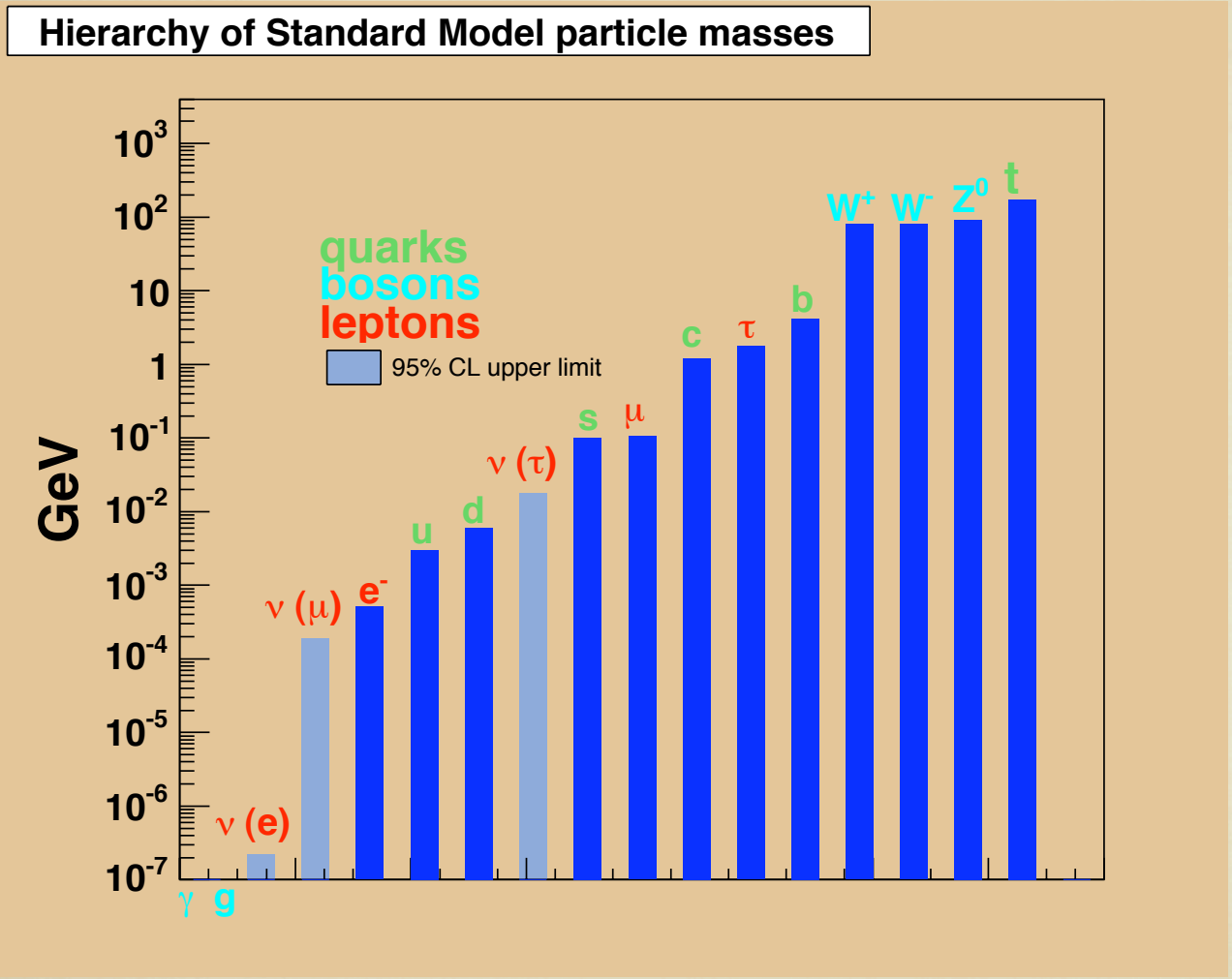
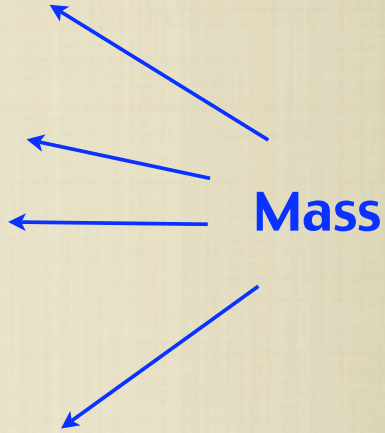
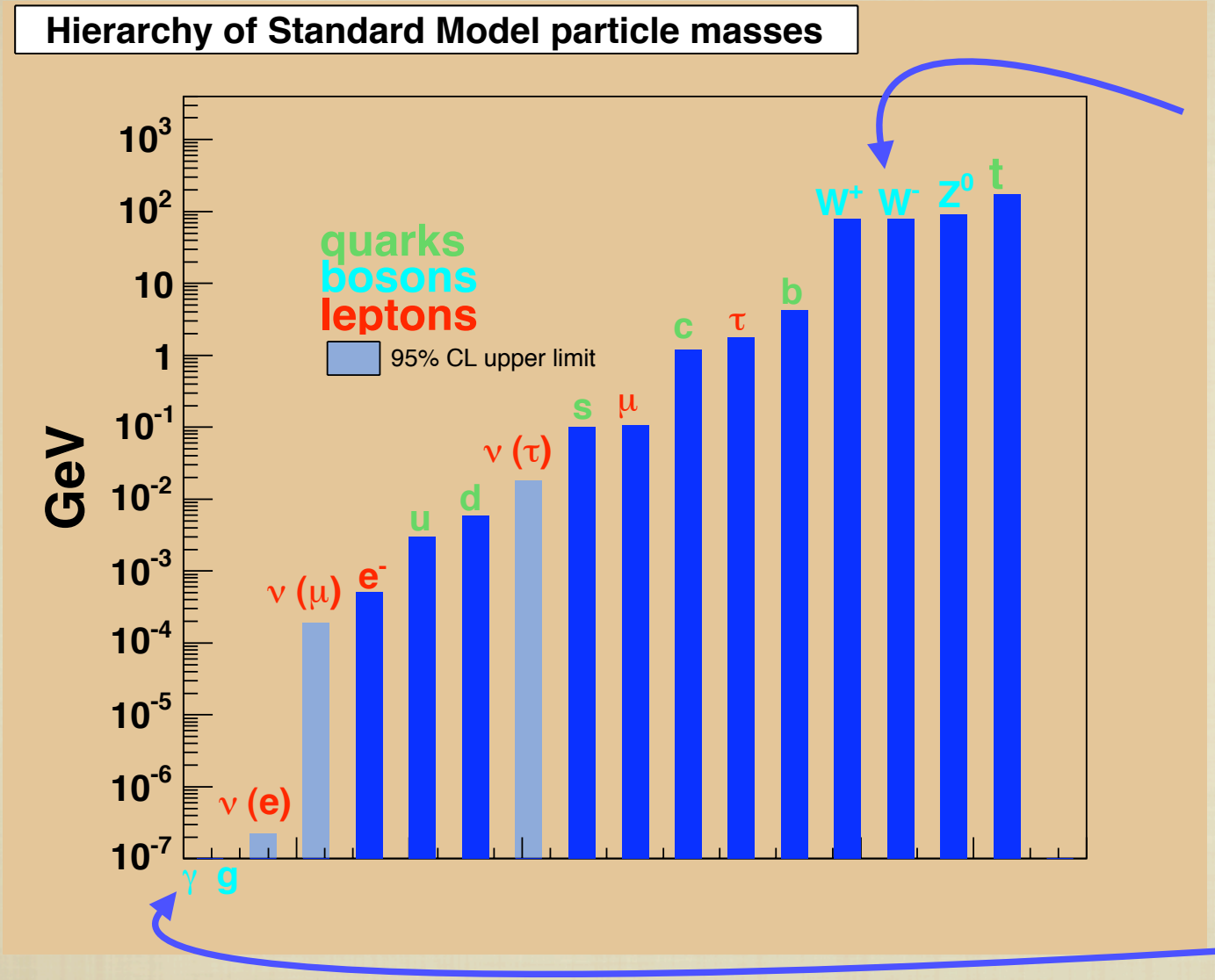


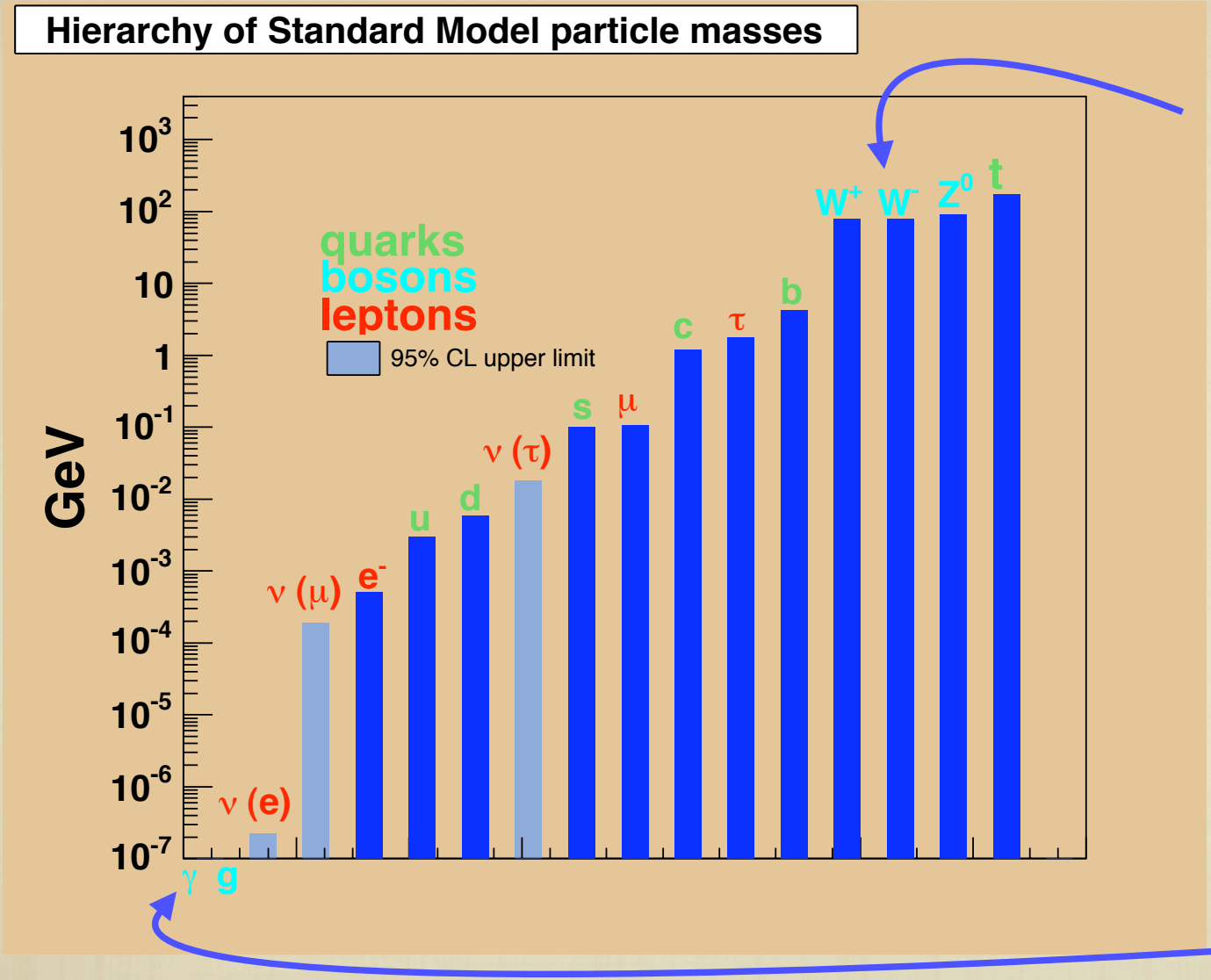


Problem 1 : Mass terms cause Standard Model calculations to fail



Weak force carriers

EM force carrier



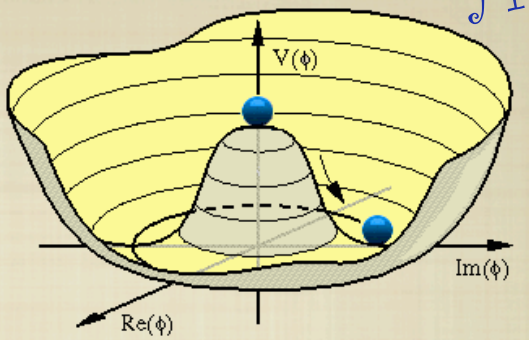
Weak force carriers

EM force carrier

Problem 2 : Fundamental asymmetry between EM and weak force

Solution: Higgs mechanism

- **Add field throughout the universe**
  - Potential is symmetric
  - Ground state breaks symmetry



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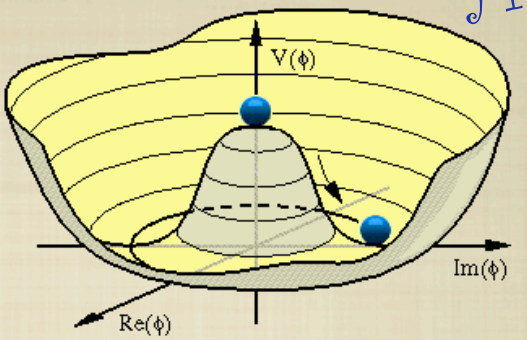

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  - W and Z bosons gain masses through degrees of freedom of Higgs field
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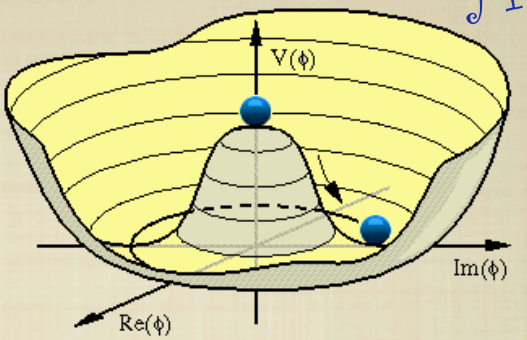

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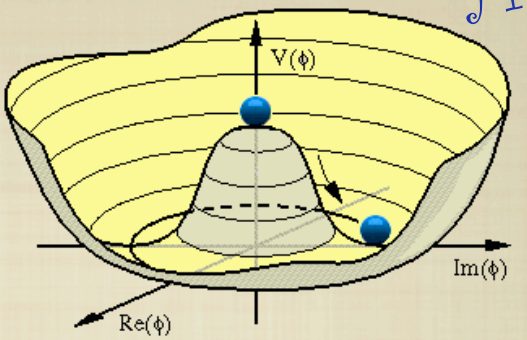

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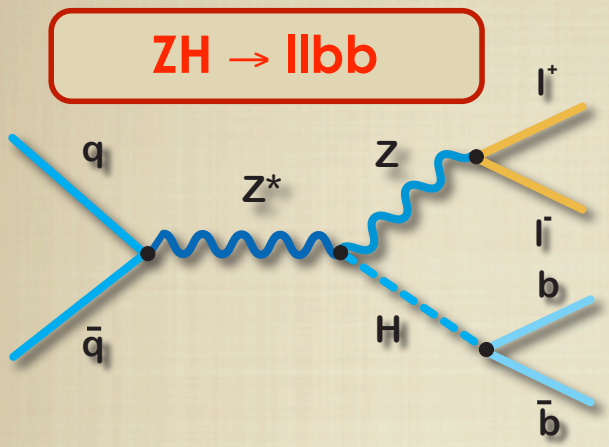
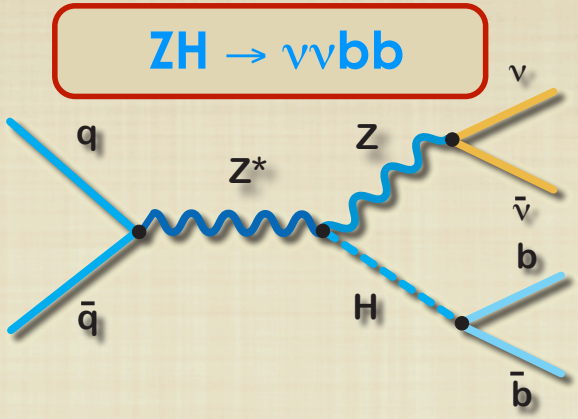
SM (with Higgs mechanism revision) tested experimentally to < 0.1%

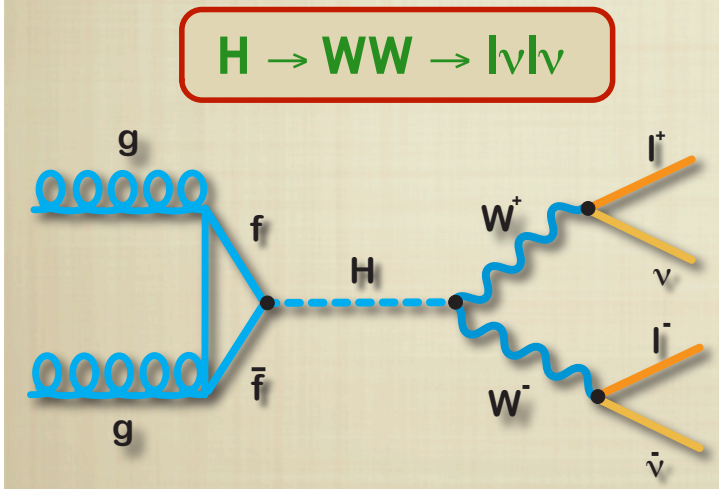
SM constraints say : Higgs mass is $87\ ^{+36}_{-27}$ GeV/c^2

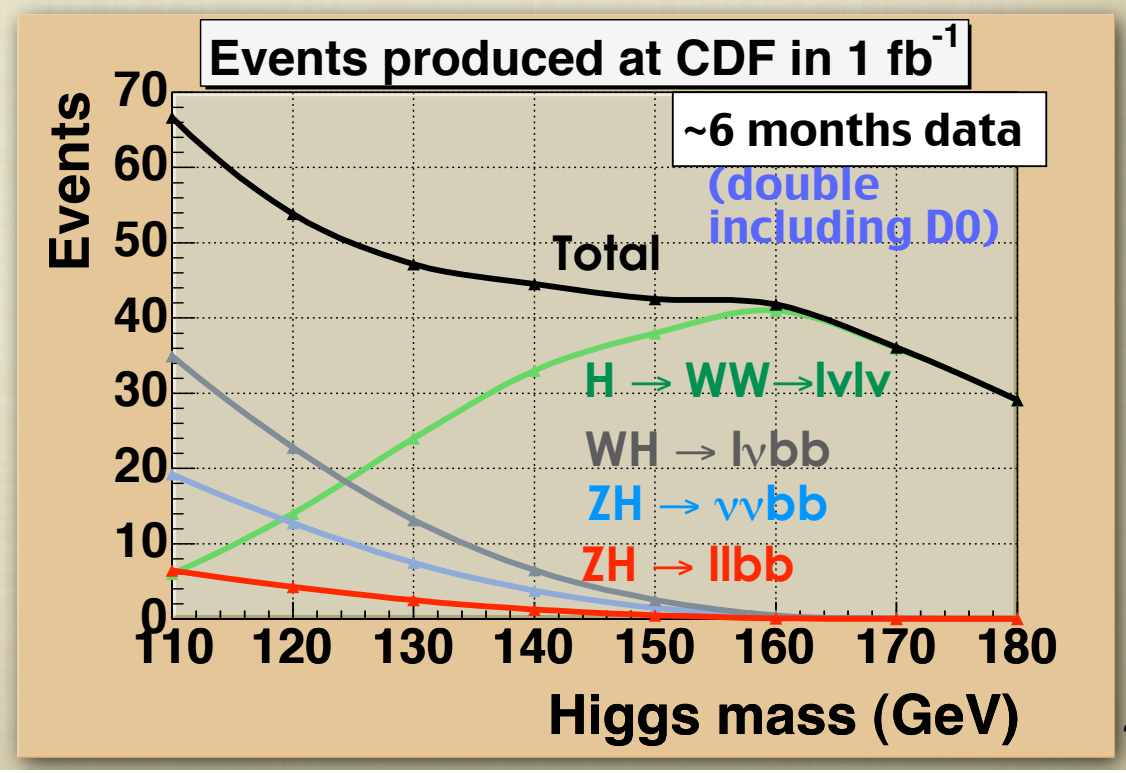
< 160 GeV/c^2 @ 95% CL

Higgs at the Tevatron









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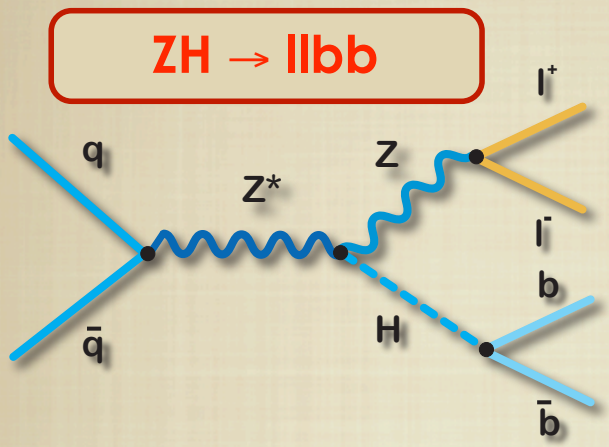

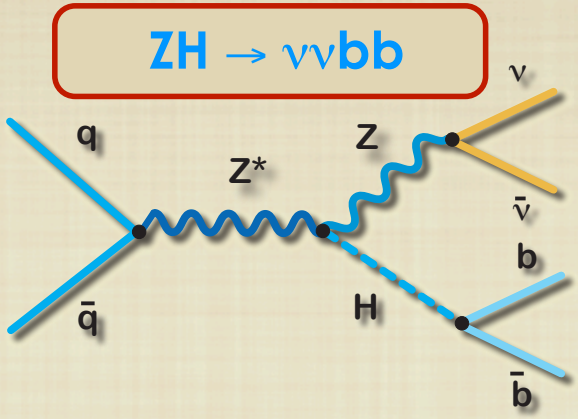

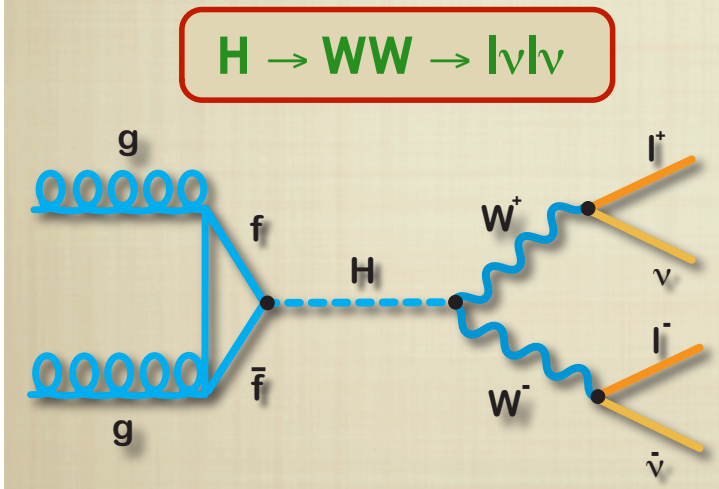

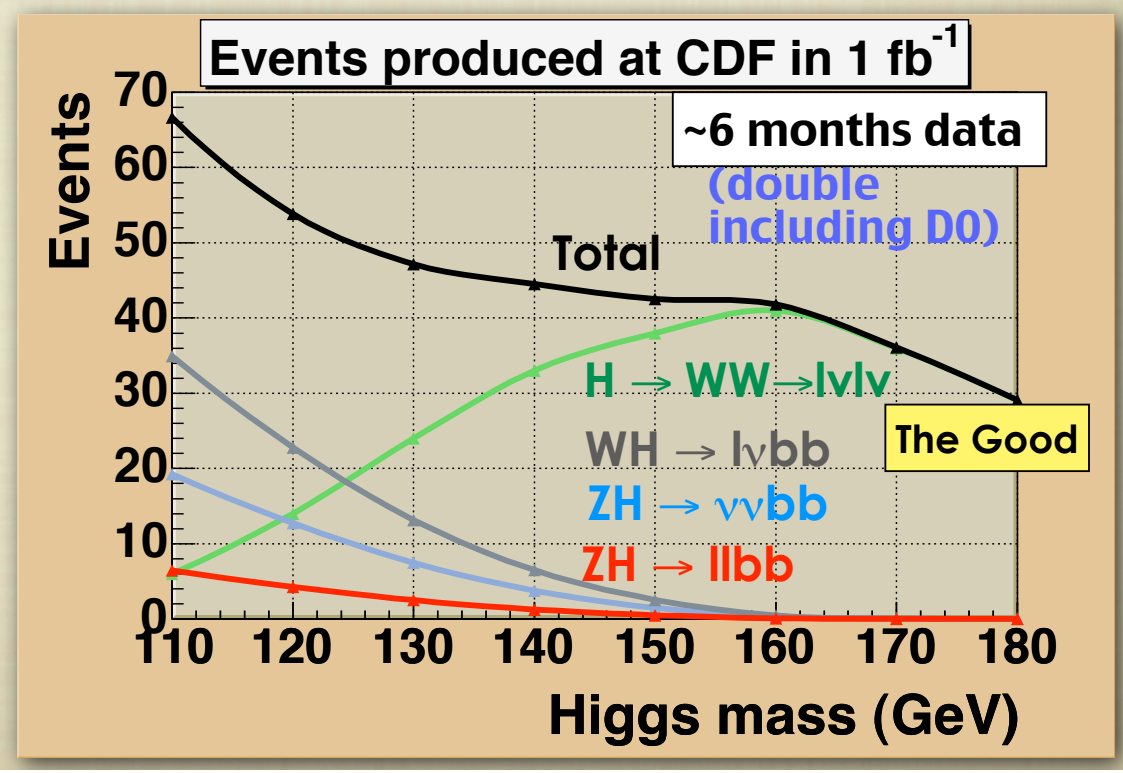

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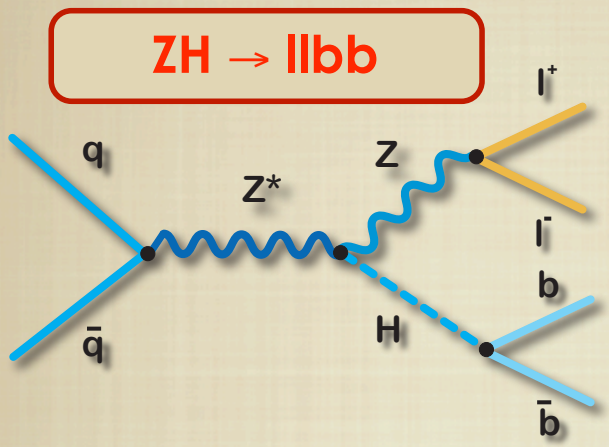

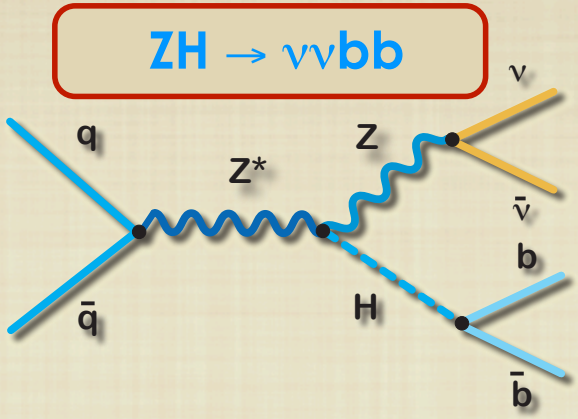

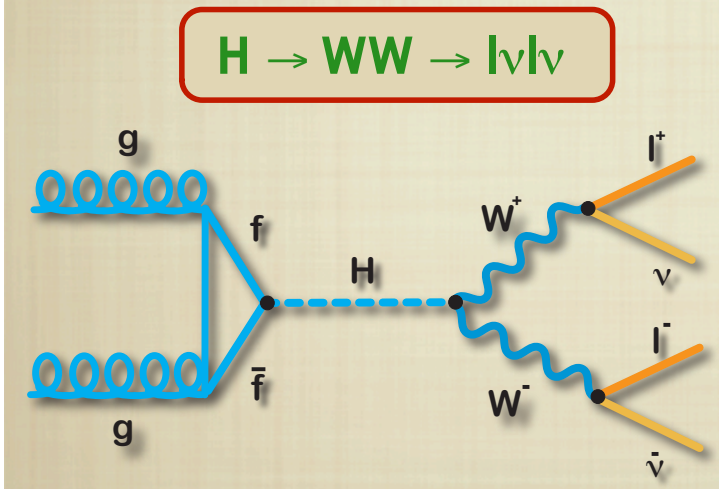

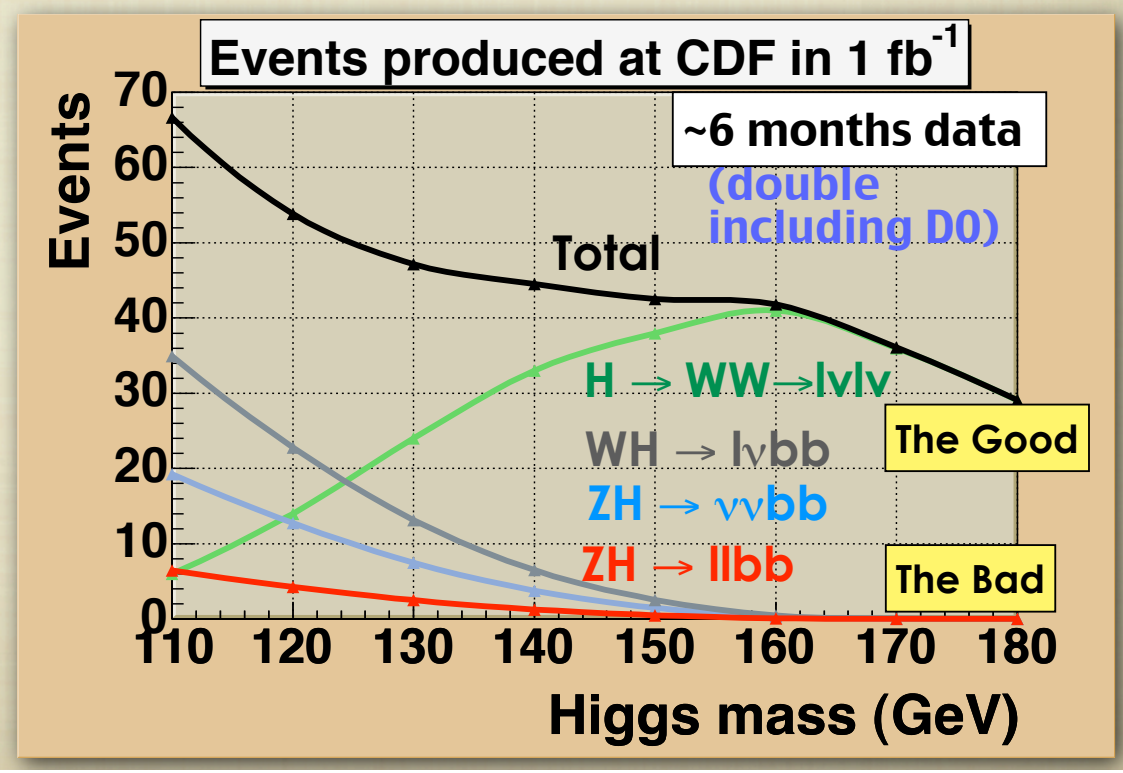

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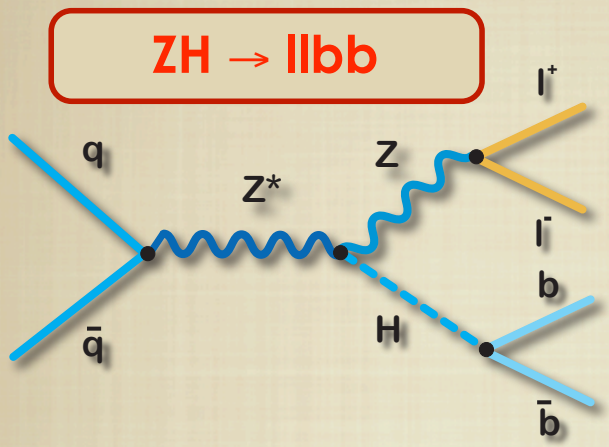

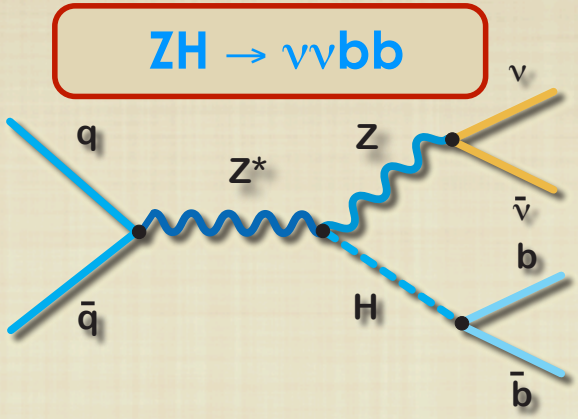

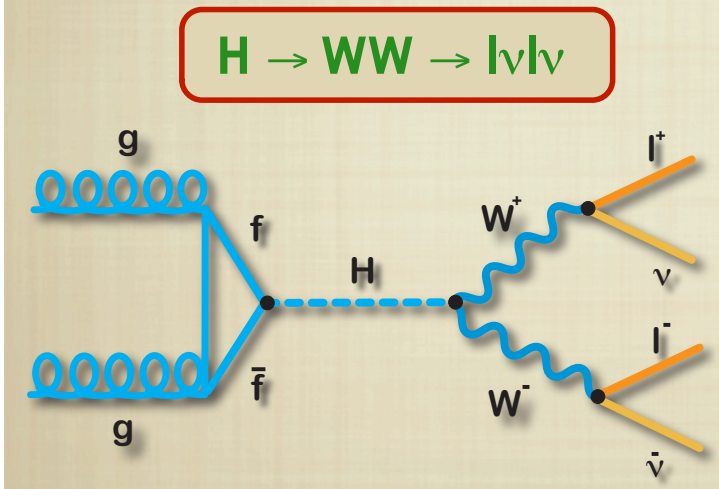

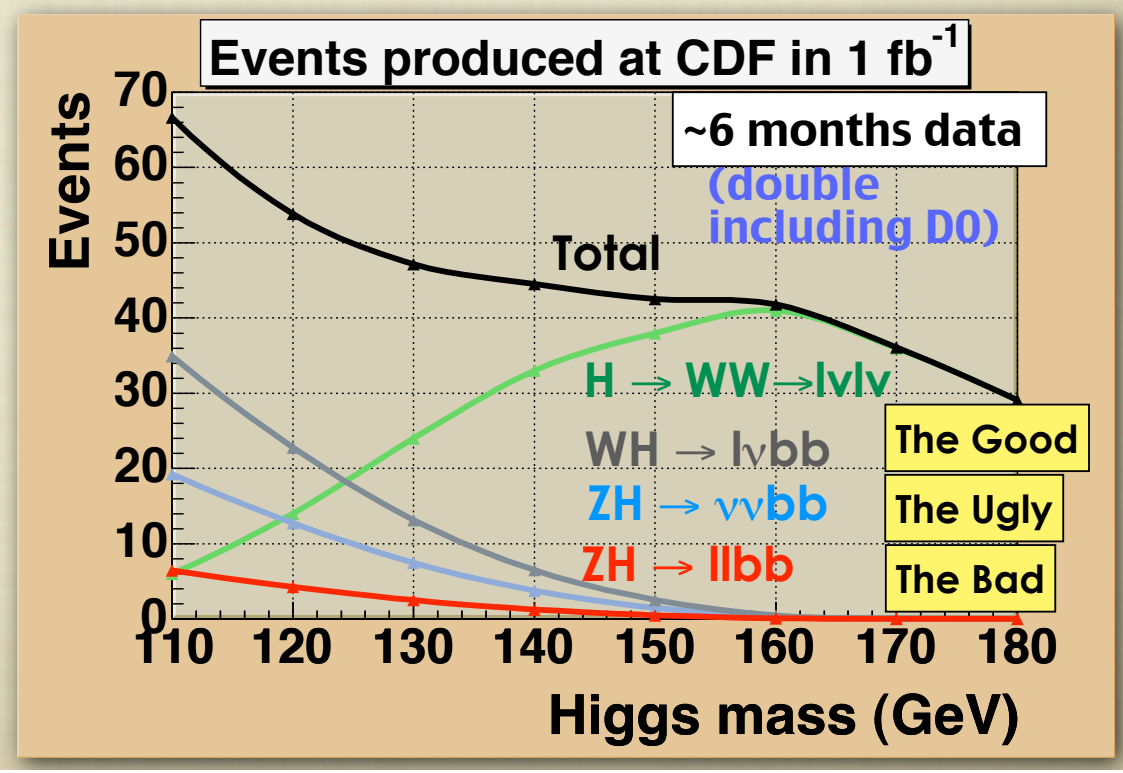

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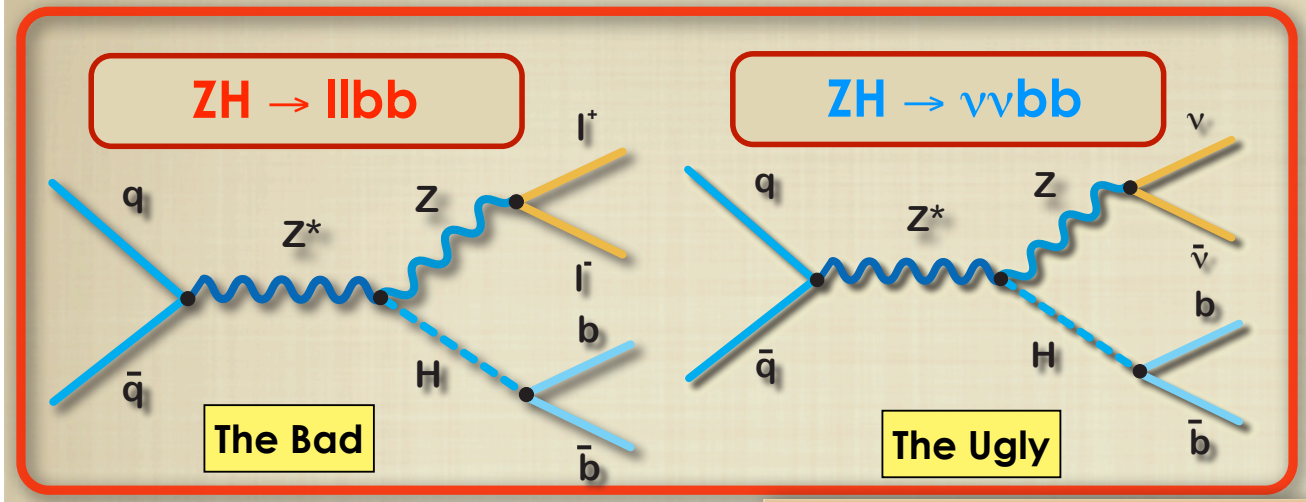
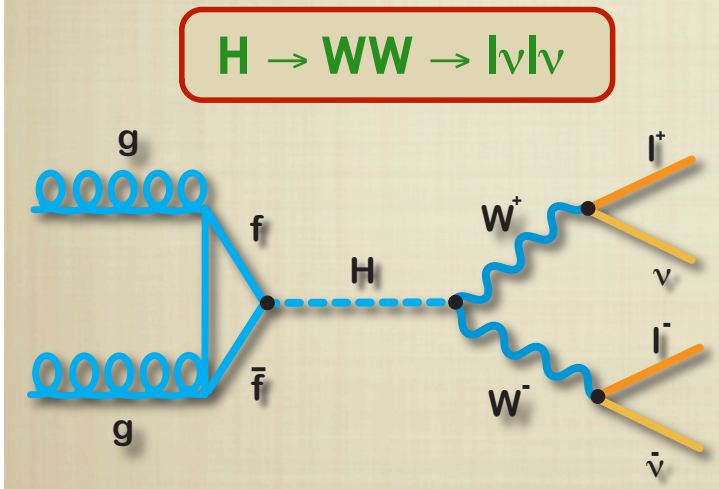
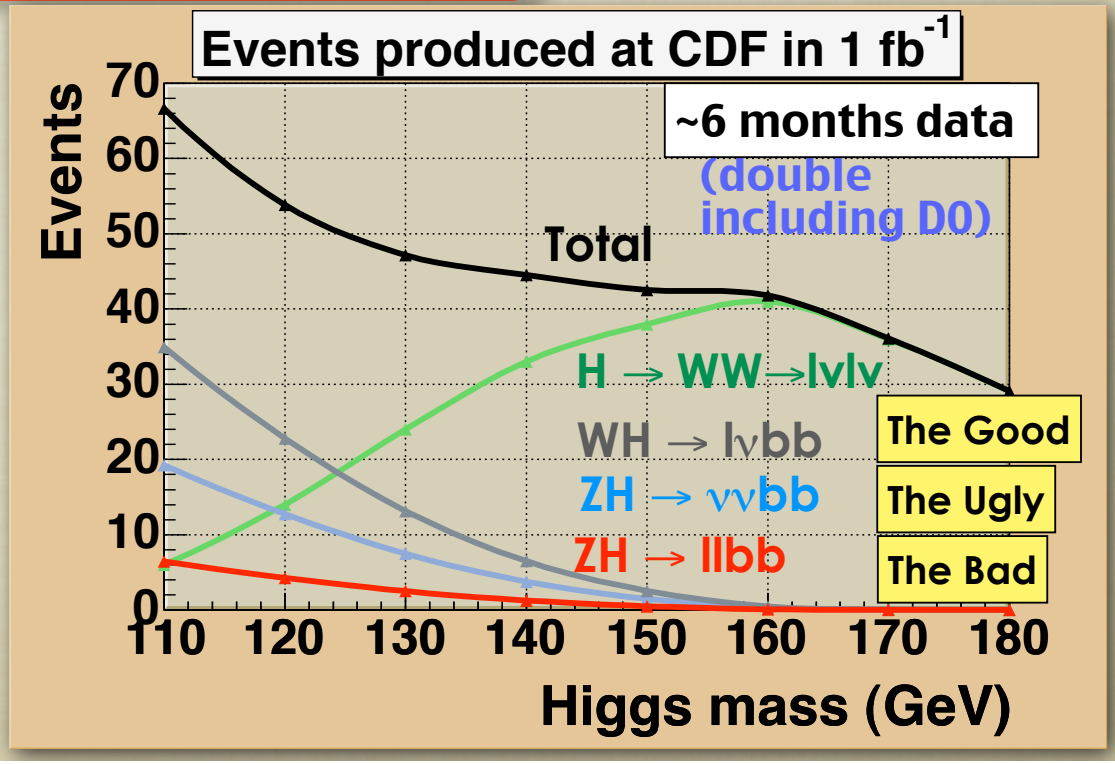
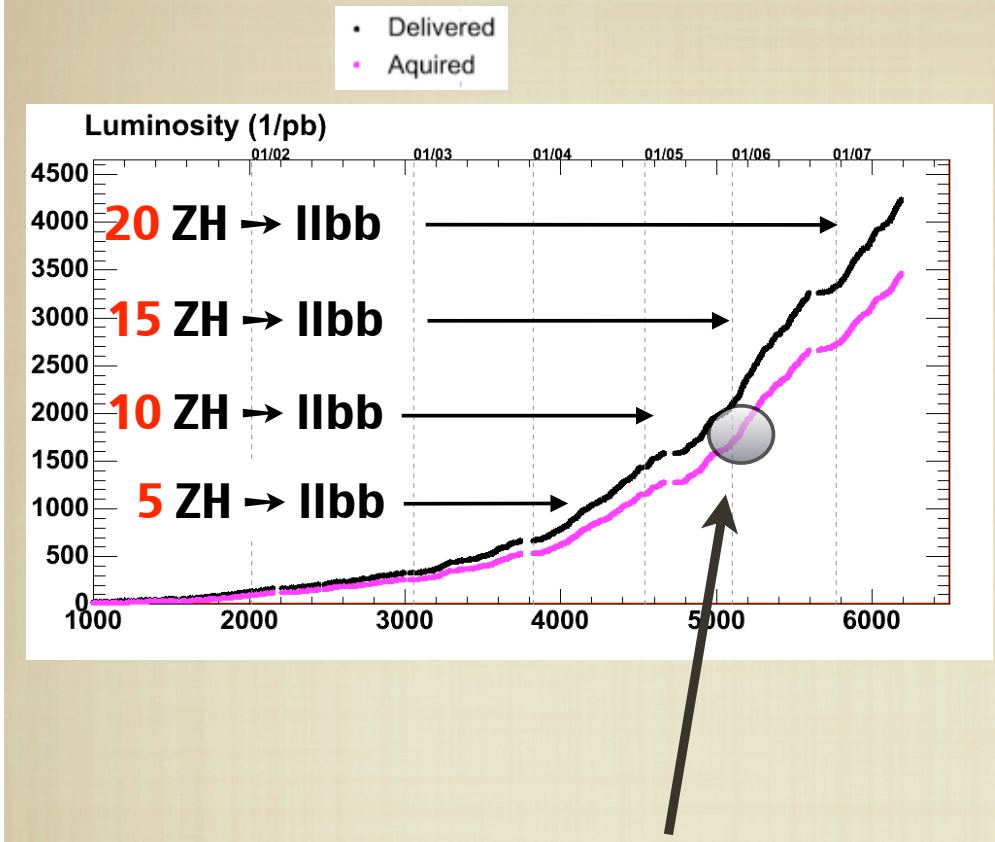






First, we need data



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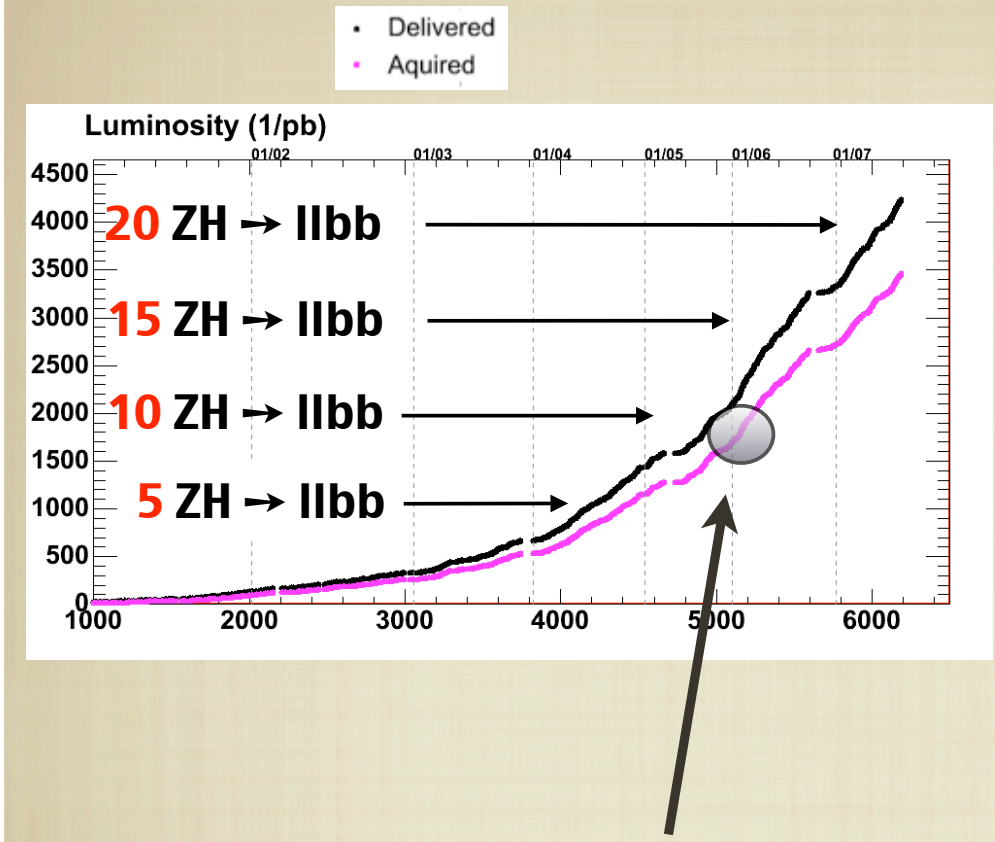

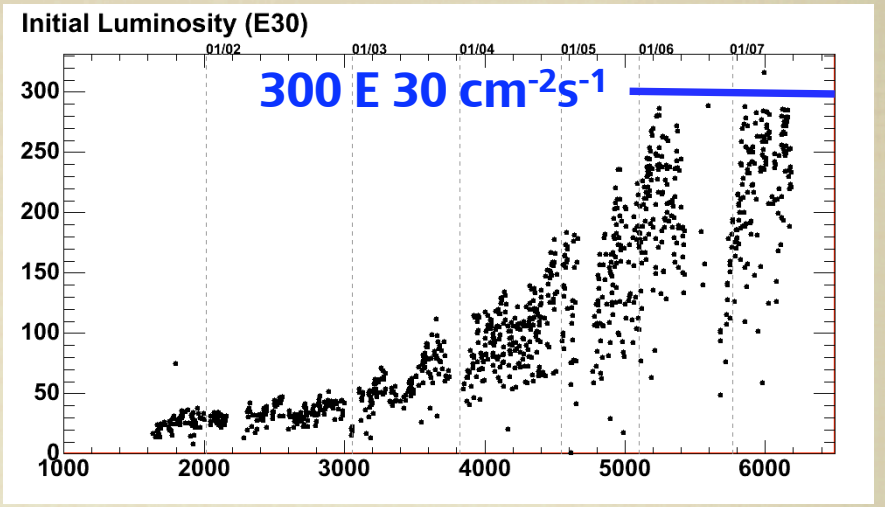

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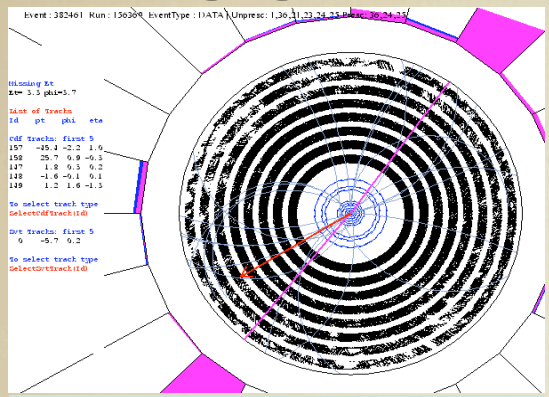
- Tevatron Peak instantaneous luminosity :
  - Above 300 E 30 $cm^{-2}s^{-1}$
    - Great news for Higgs prospects
    - But challenge to collect Higgs events

Triggering on ZH →l^+l^-bb



Z → ee at 300E30 $cm^{-2}s^{-1}$
7 interactions per crossing

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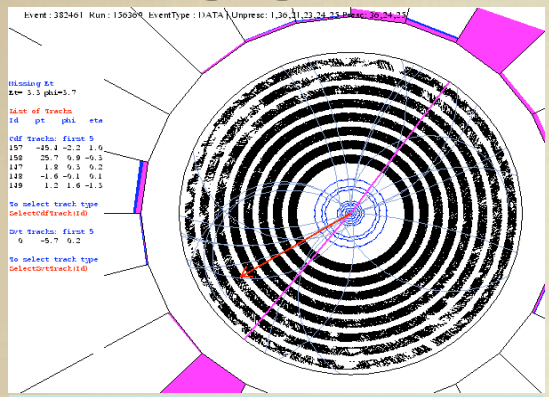

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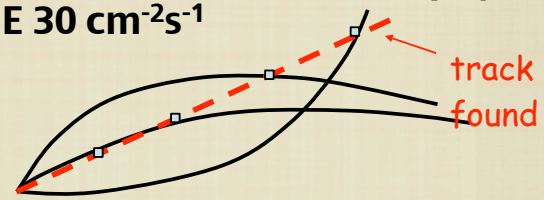

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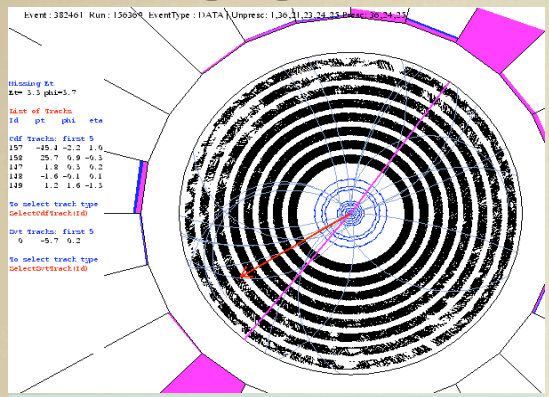

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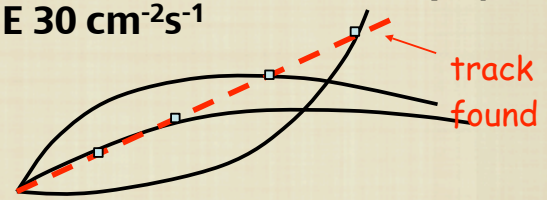

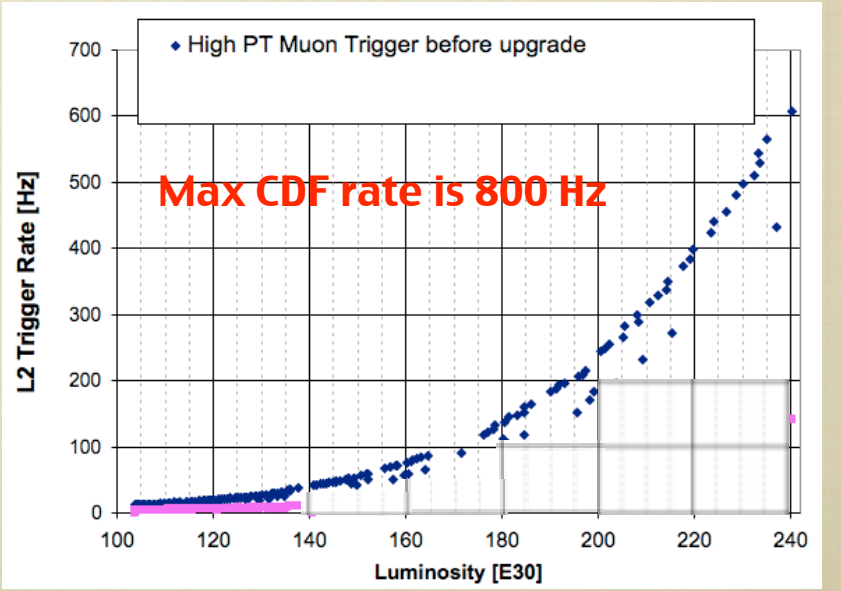

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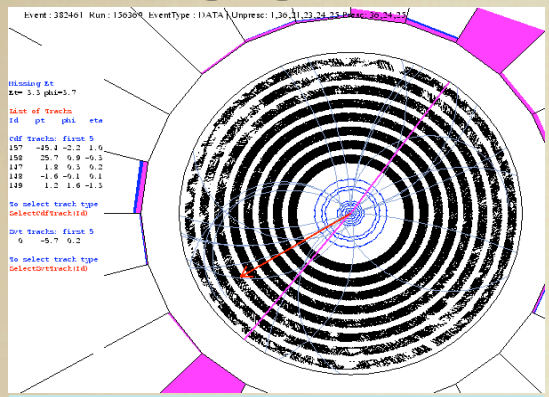

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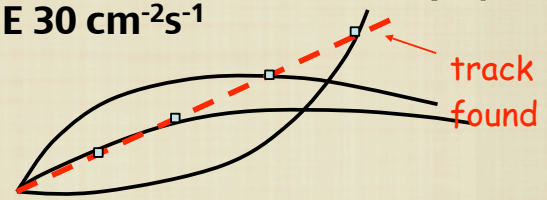

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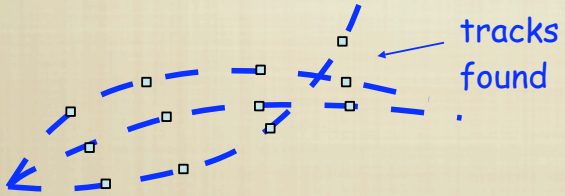

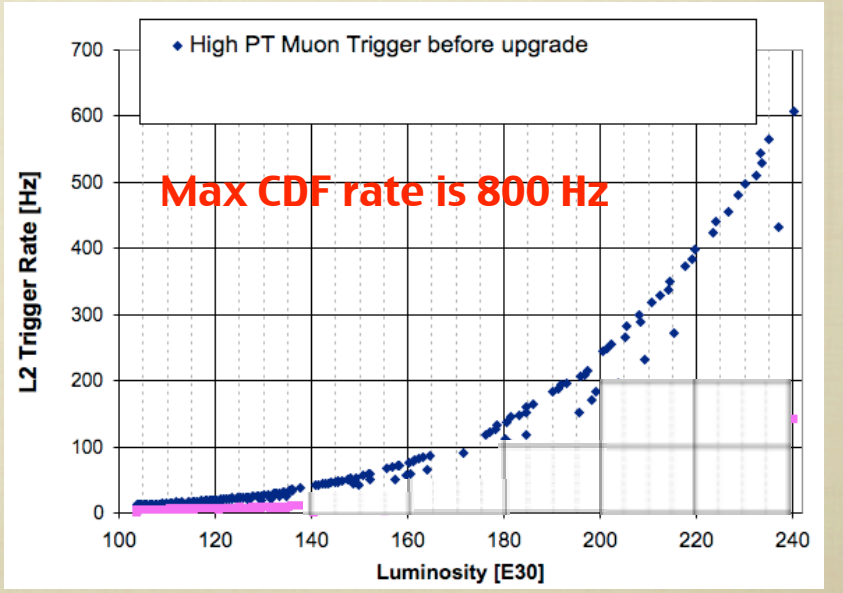

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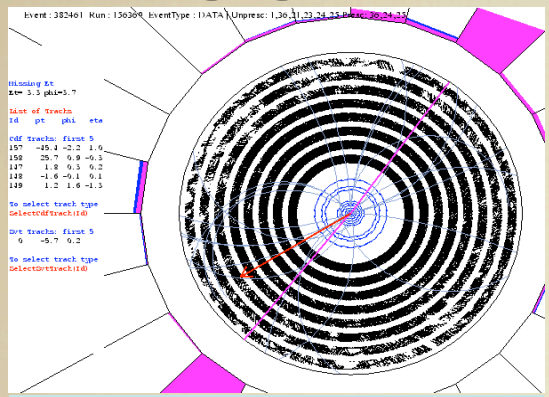

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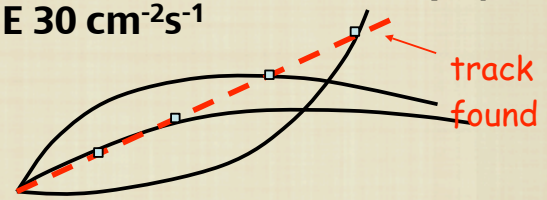

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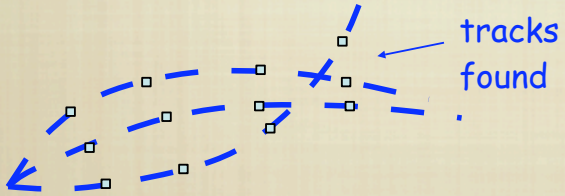

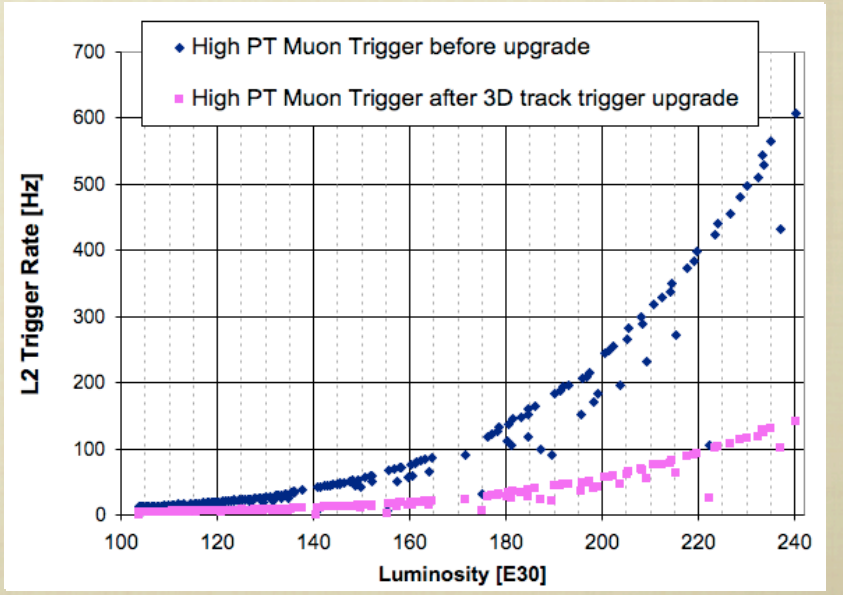

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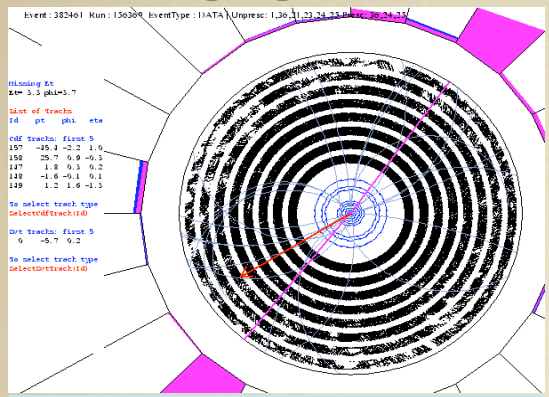

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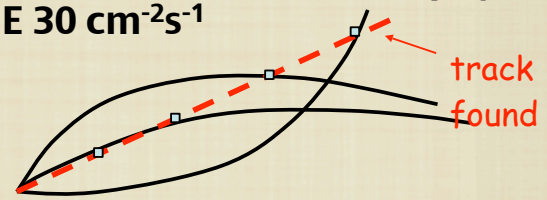

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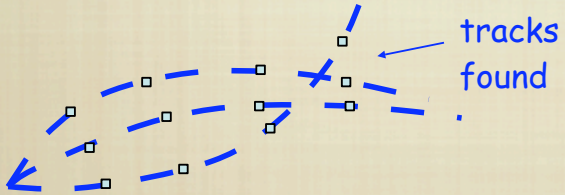
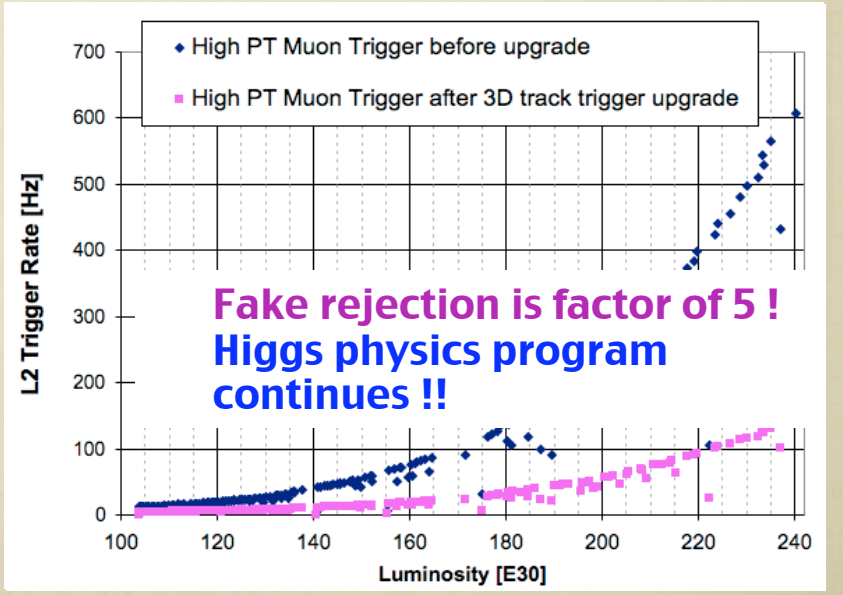
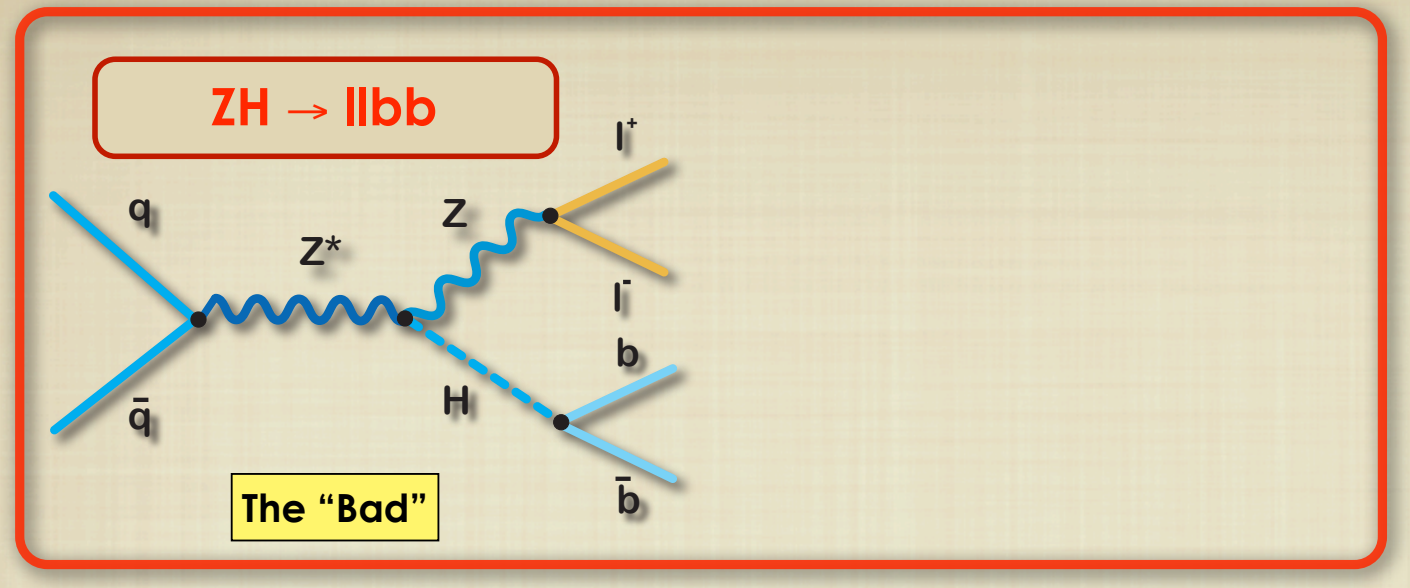




Searches for ZH



ZH → llbb

- Challenges
  - Smallest Higgs signal
    - Impact considered minimal by 2000 Tevatron Higgs report
- Advantages
  - Only fully constrained channel
  - Both Z and H resonances
  - Fake lepton backgrounds small
- Can we make this channel competitive ?

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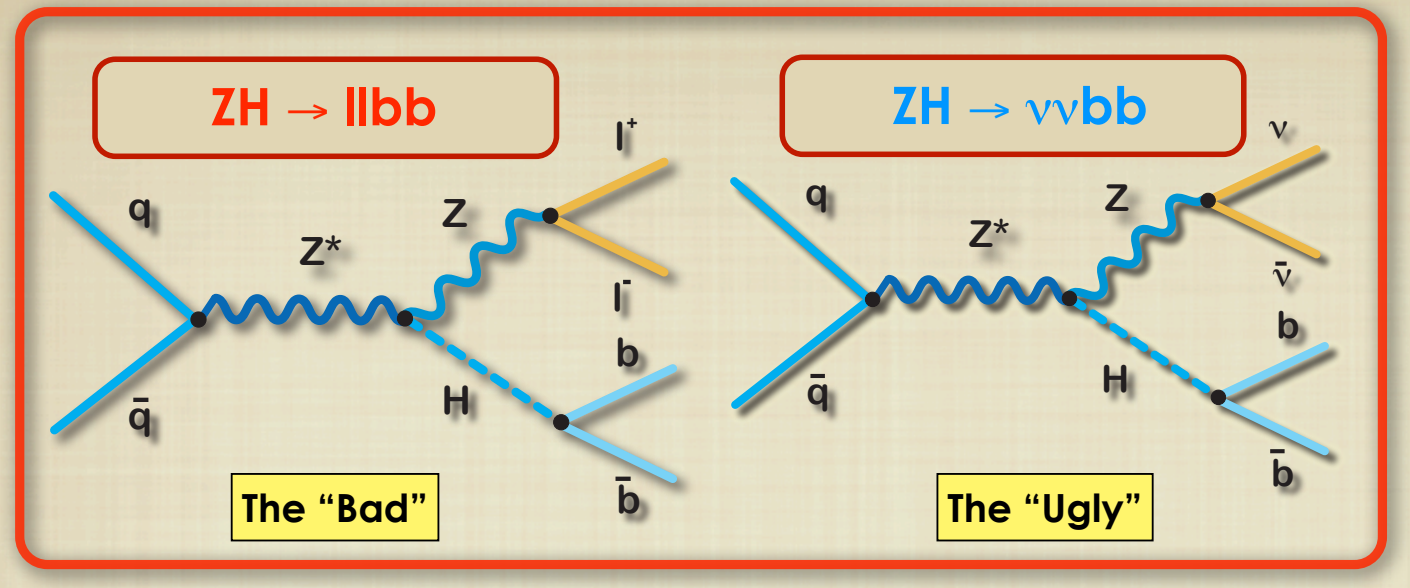

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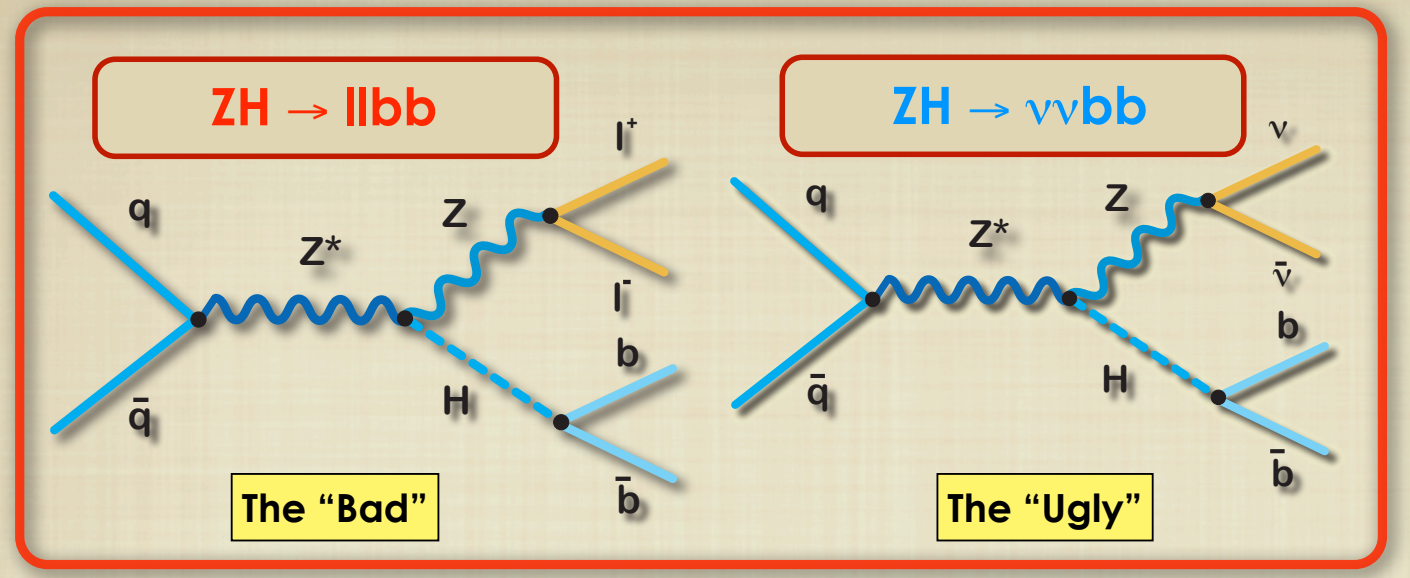
  - Smallest Higgs signal
    - Impact considered minimal by 2000 Tevatron Higgs report
- Advantages
  - Only fully constrained channel
  - Both Z and H resonances
  - Fake lepton backgrounds small
- Can we make this channel competitive ?

Searches for ZH



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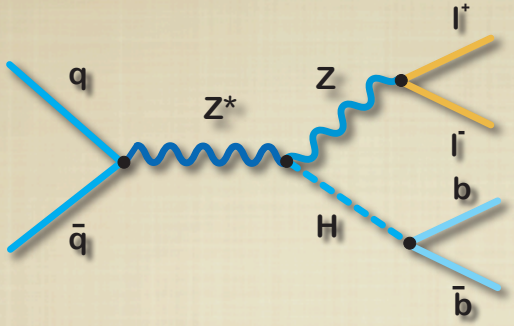
ZH → νν̄bb

- Challenges
  - Troublesome backgrounds
    - Mismeasured jets & leptons create missing energy
- Advantages
  - 3X signal than ZH → llbb
  - Added signal from WH → lνbb when lepton is missed
- Can we separate large signal from difficult backgrounds ?

Let's do a counting experiment to find ZH →llbb



Selection	Signal m_H = 115 GeV (Events) in 1 fb^{-1}	Background (Events)	BKG uncertainty in units of expected SM cross-section (1σ stat. only)
Produced in CDF	5	100,000,000,000,000	2,000,000*SM

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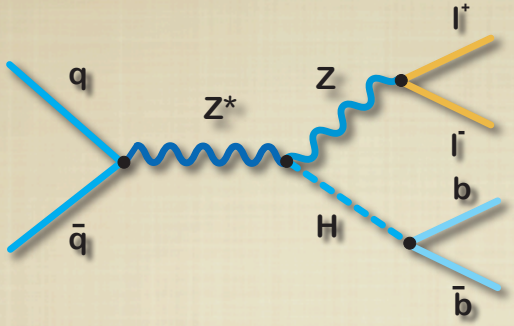

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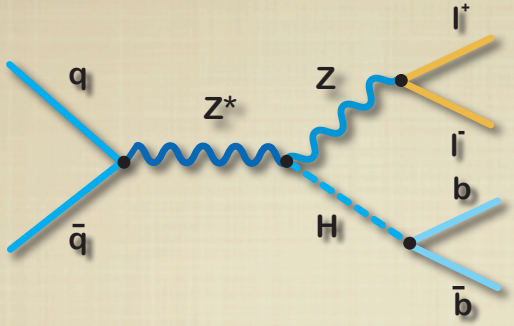

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Select Z boson	1.5	150,000	300*SM

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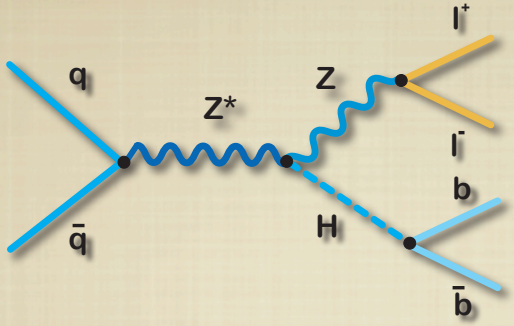

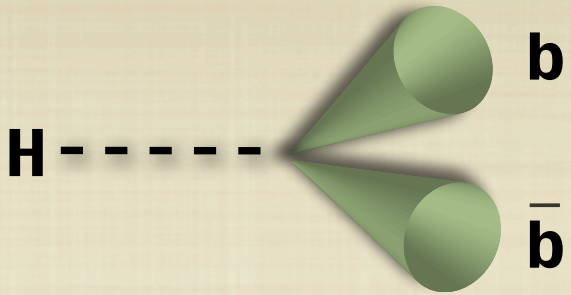

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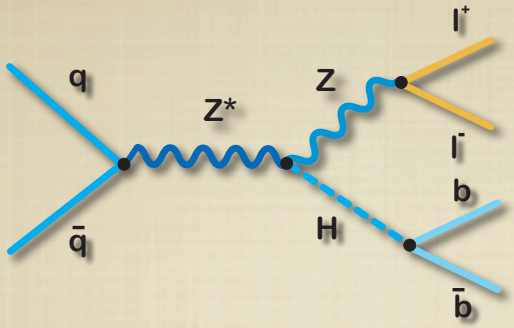

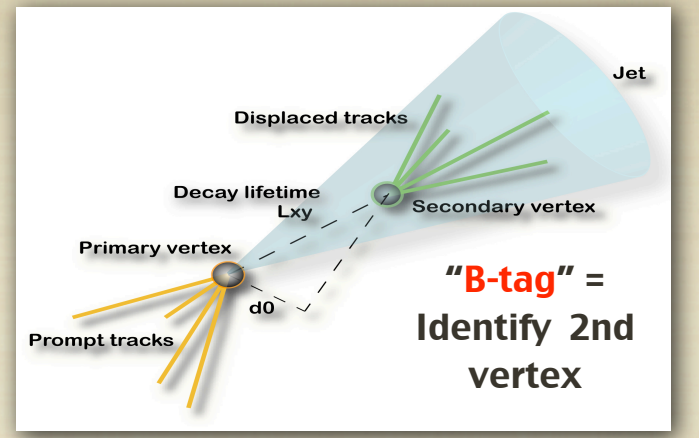

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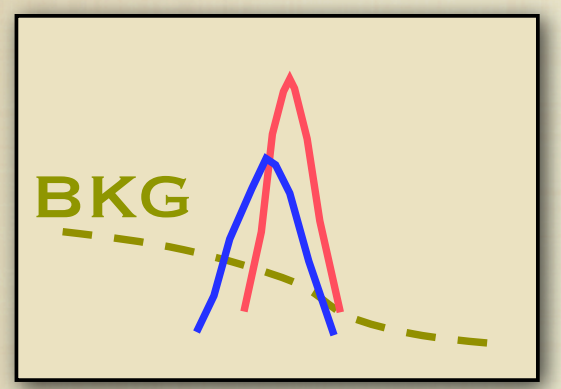
Produced in CDF	5	100,000,000,000,000	2,000,000*SM
Select one lepton	3	100,000,000	3,000*SM
Select Z boson	1.5	150,000	300*SM
Select 2 jets	1	3,000	50*SM
Require b-tag(s)	0.7	100	15*SM

- Backgrounds are 75% Z+jets after these cuts

Distinguishing Z+jets from ZH

- Best sensitivity to H→bb should be with M_{bb}
  - Easier to find Higgs if dijet mass resolution is narrower



Less background
under narrower signal

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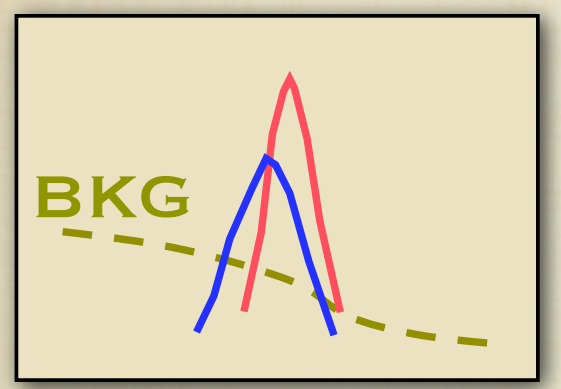

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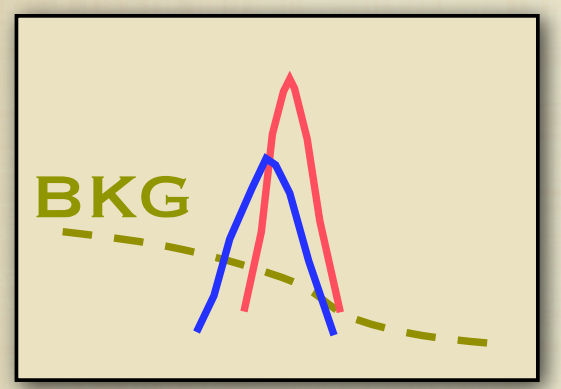

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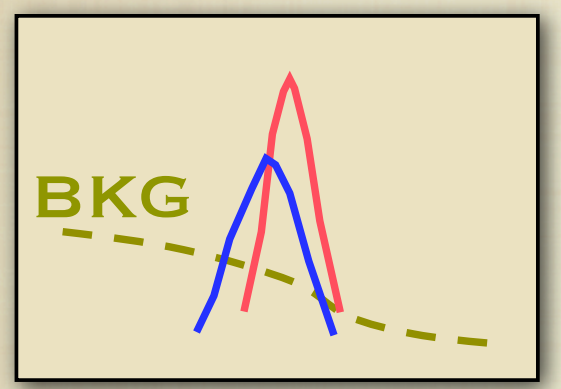

Less background under narrower signal

Where's Higgs ?

Using MET to improve M_{jj}

- In ZH → llbb, there should be no missing transverse energy (MET)
  - Leptons measured well
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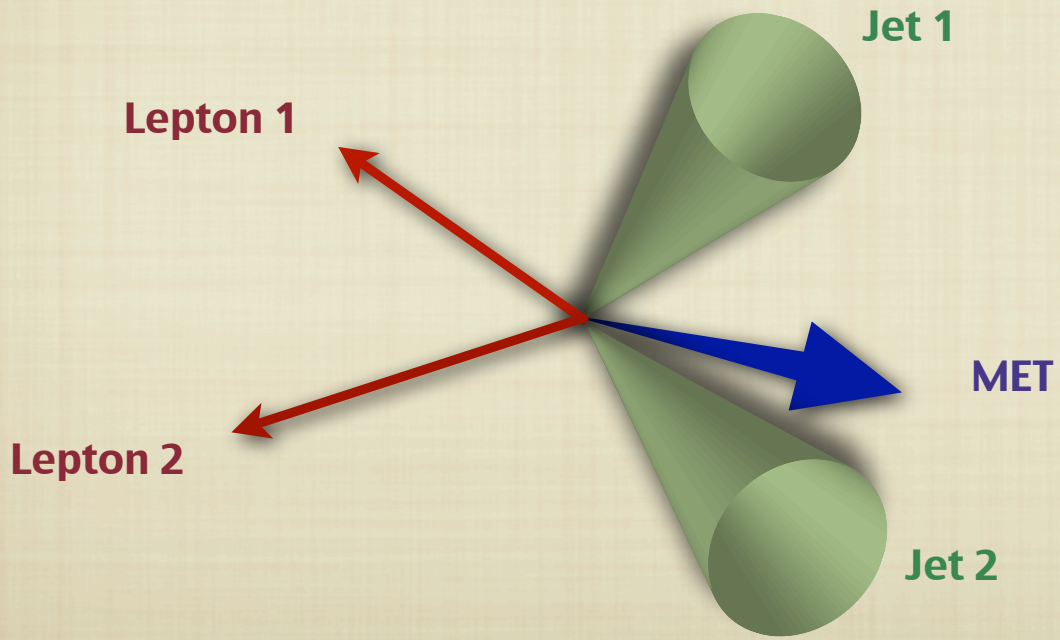

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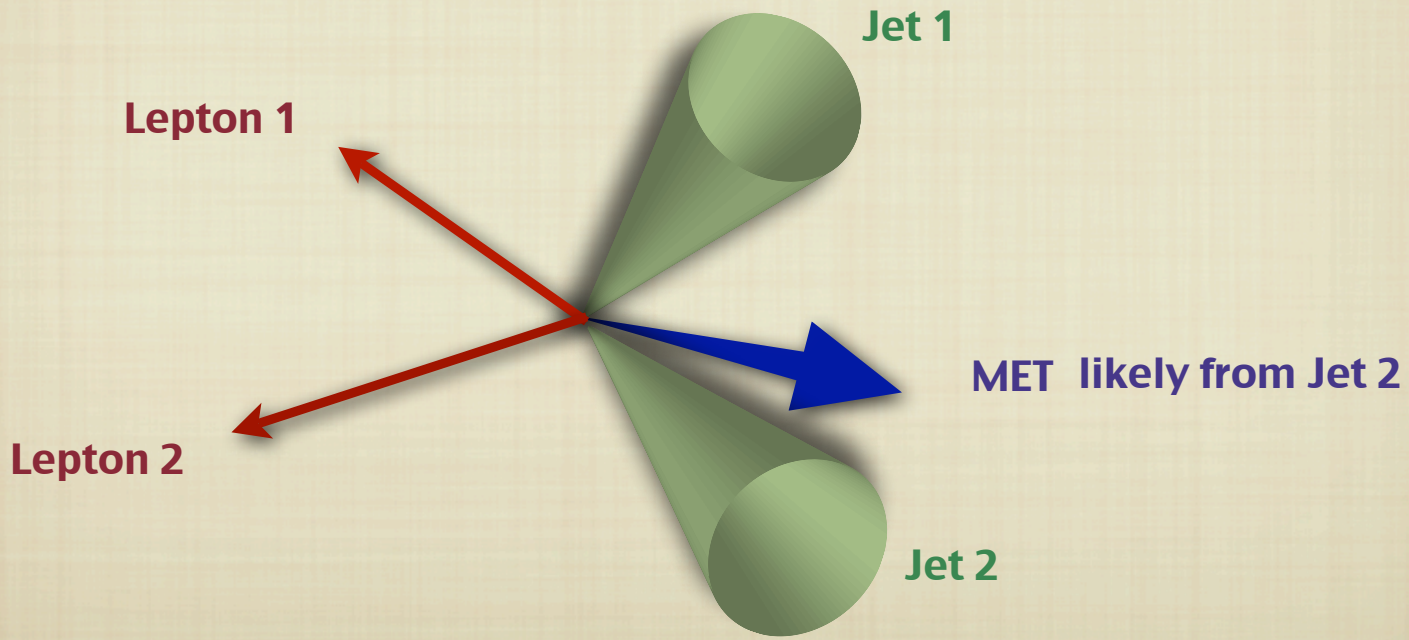

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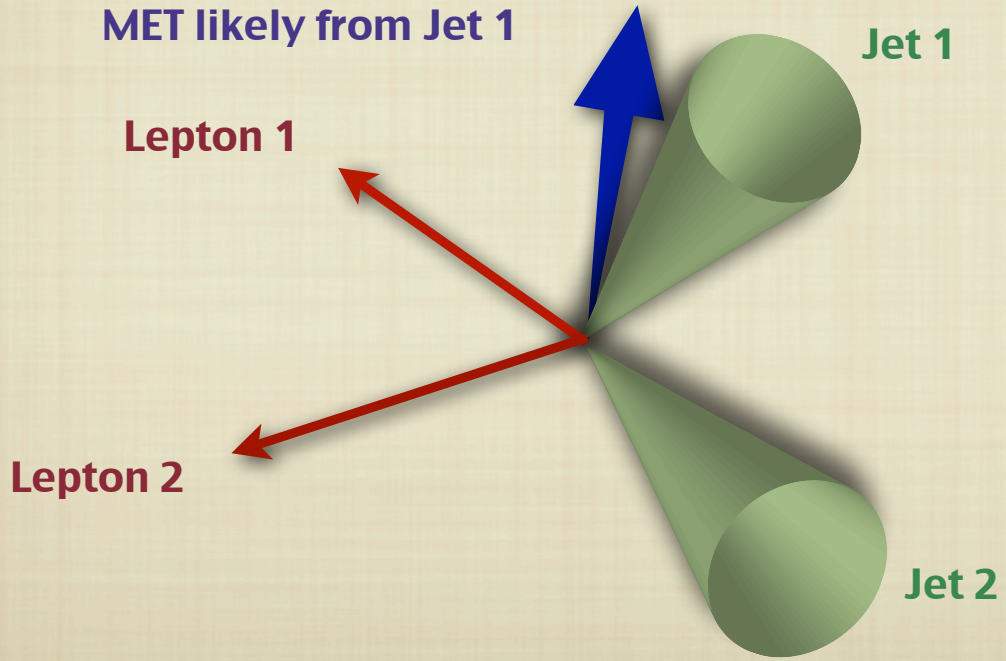

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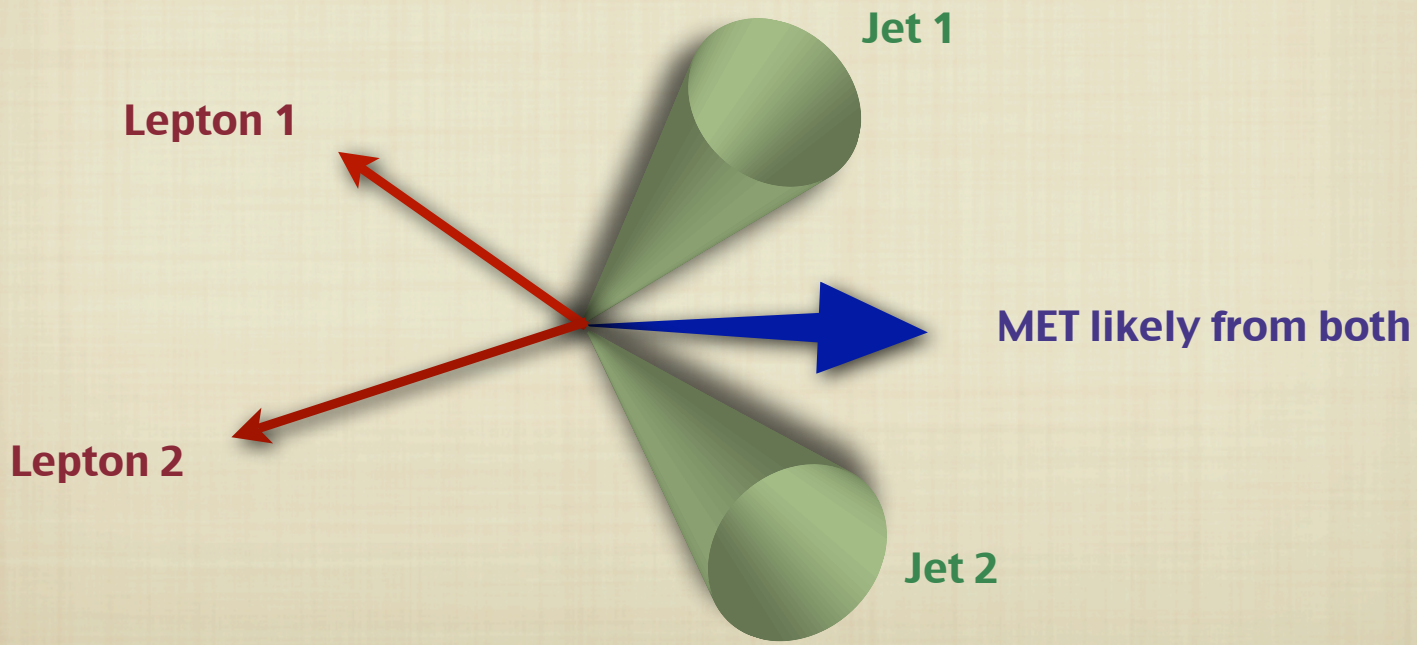
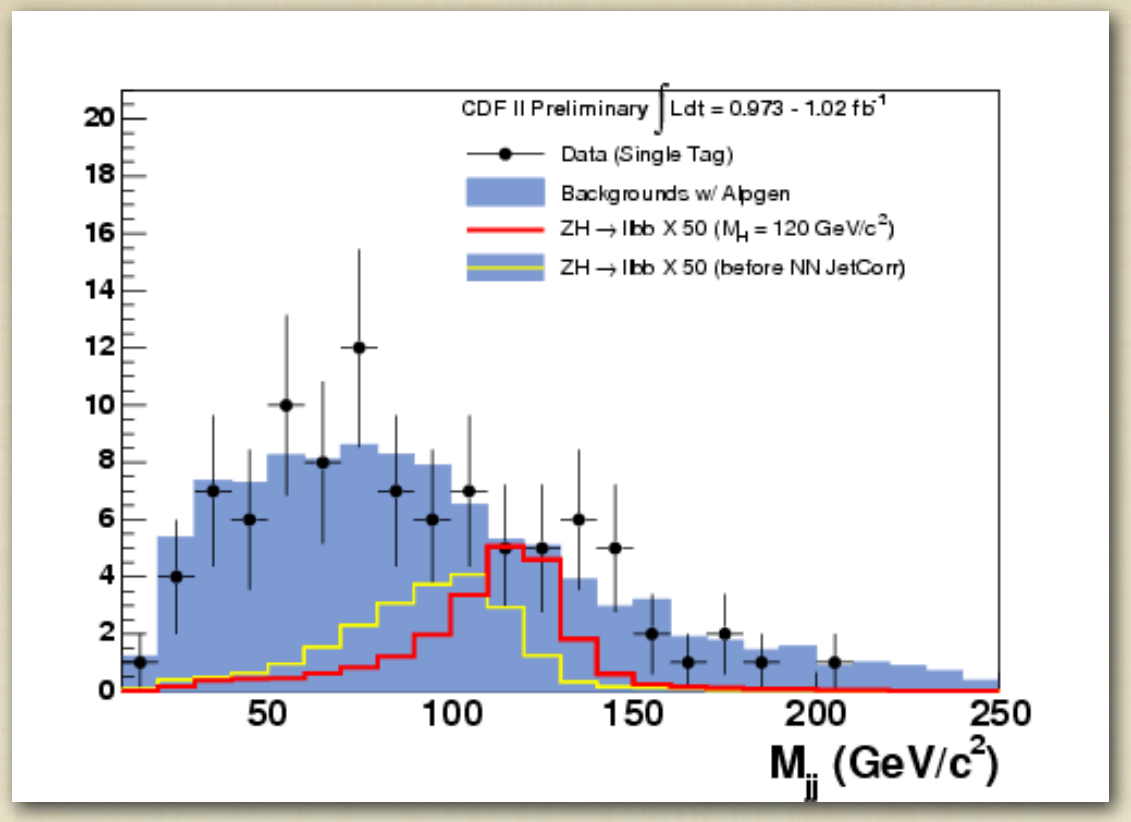


Resulting M_{jj} improvement

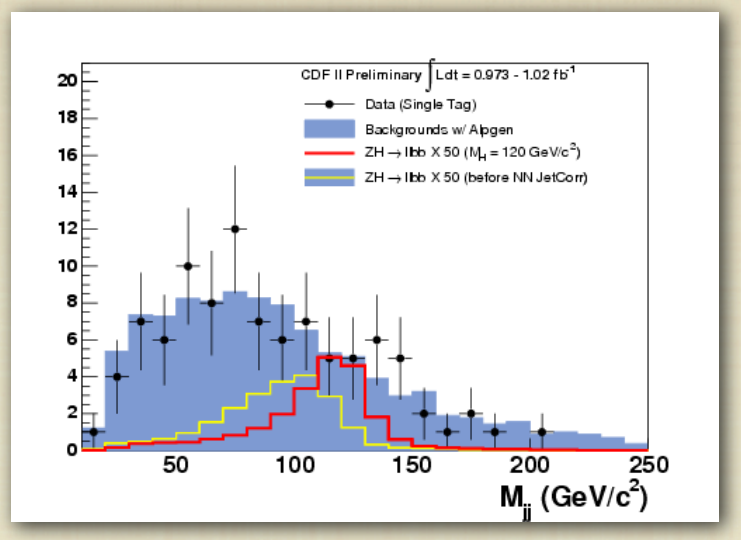


M_{JJ} one b-tag data

- We do a kinematic fit to assign MET to jets
- For events w/ two b-tags, dijet mass resolution improves from 18% to 11%

Multivariate Higgs identification

- Dijet mass is good discriminant but not best



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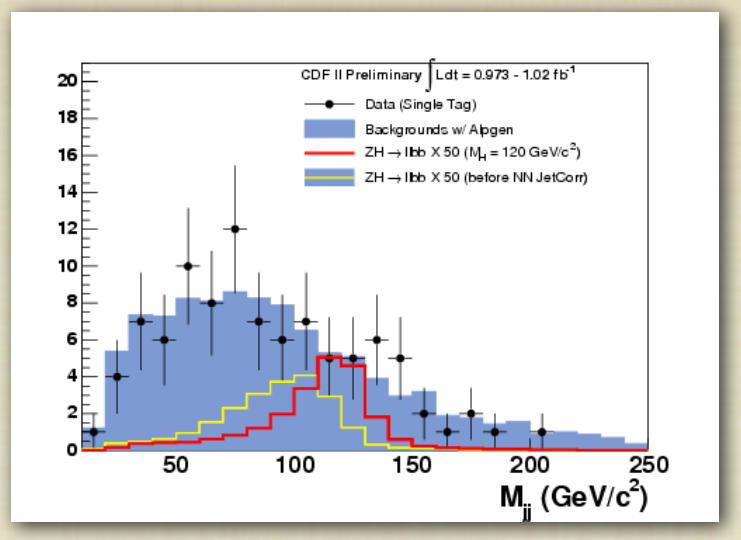
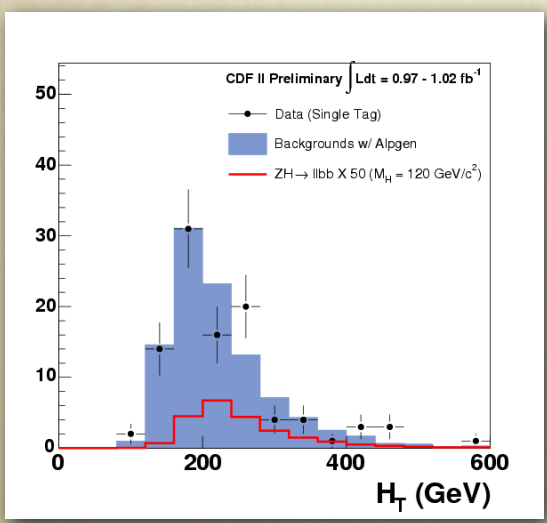
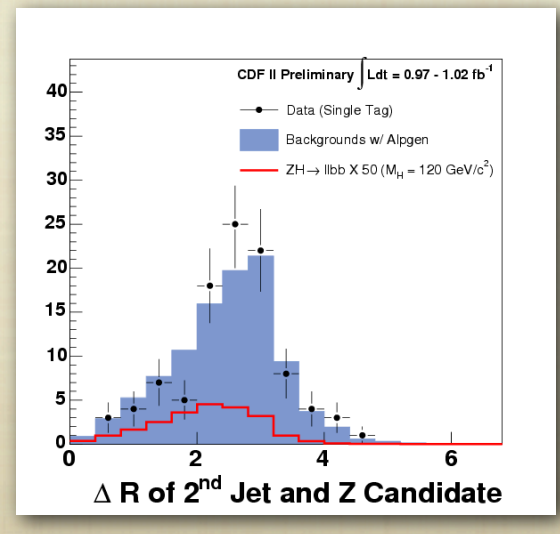
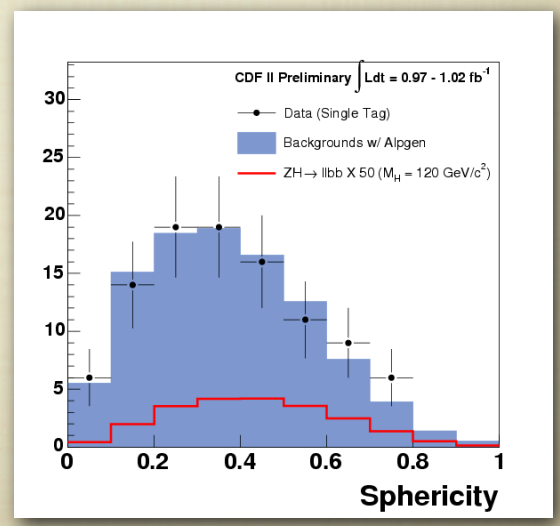


- Better to use multiple distributions which all separate signal from background

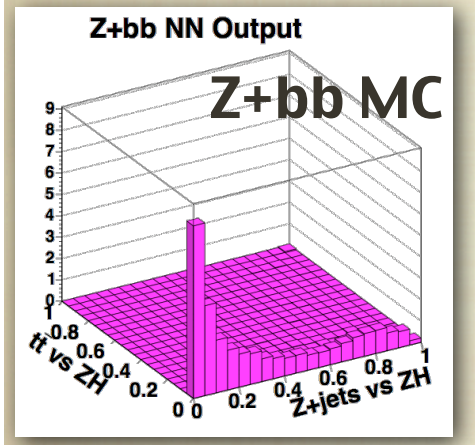


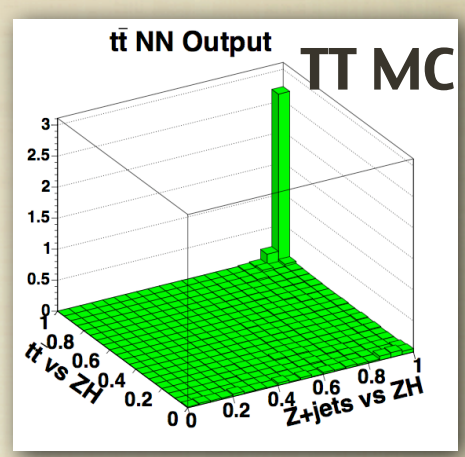


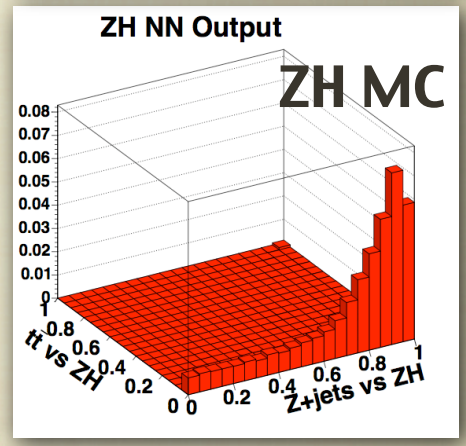


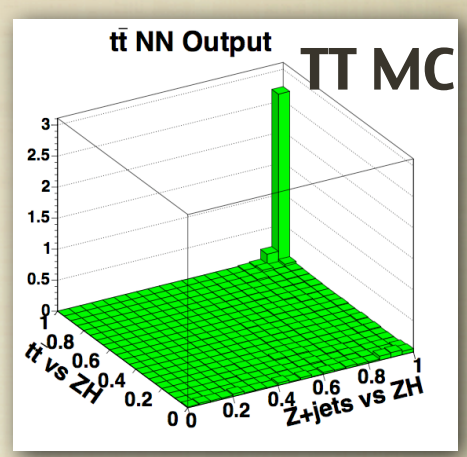
Backgrounds are different from signal in different ways

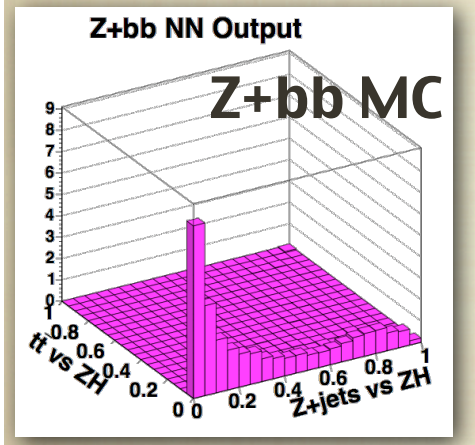
- We can train a Neural Network discriminant in 2 dimensions

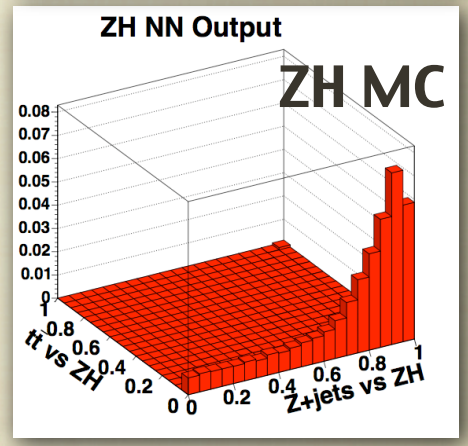




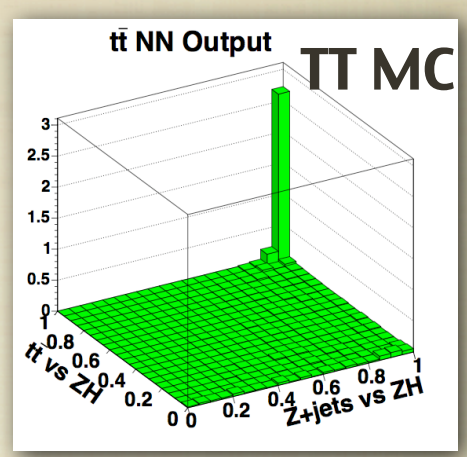


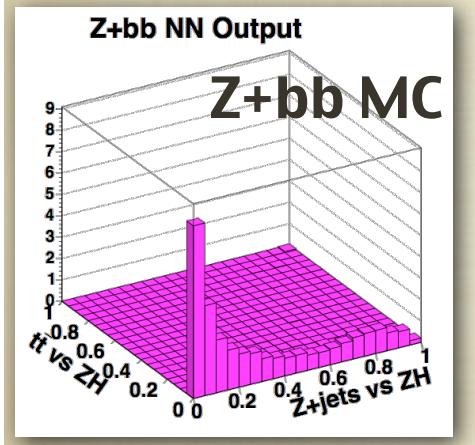

tt̄ NN Output
TT MC
tt̄ vs ZH
Z+jets vs ZH

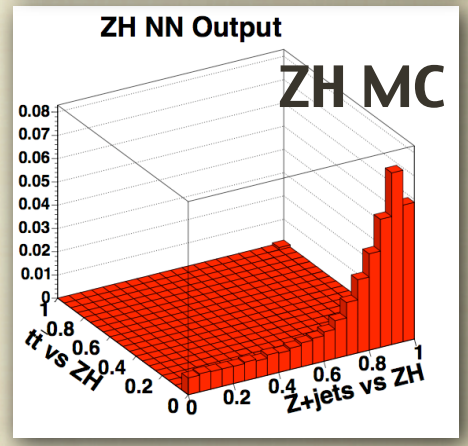

Z+bb NN Output
Z+bb MC
tt̄ vs ZH
Z+jets vs ZH


ZH NN Output
ZH MC
tt̄ vs ZH
Z+jets vs ZH

Data: Before b-tagging

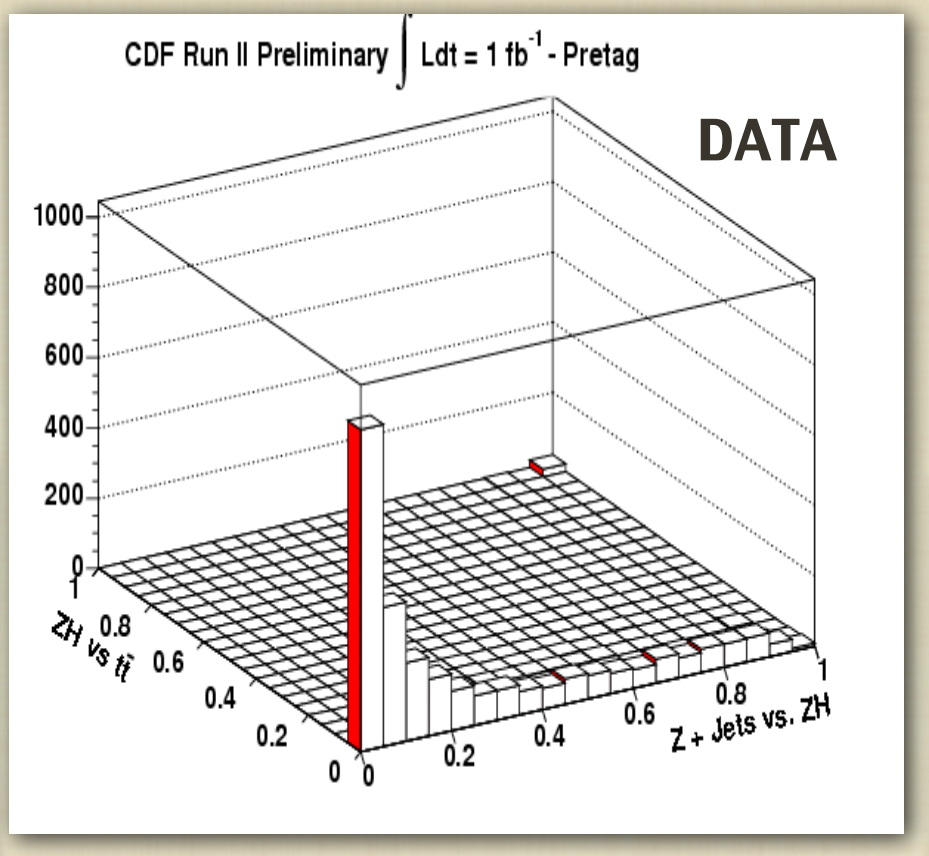


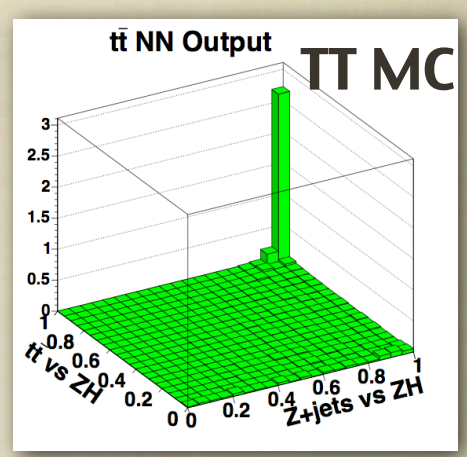


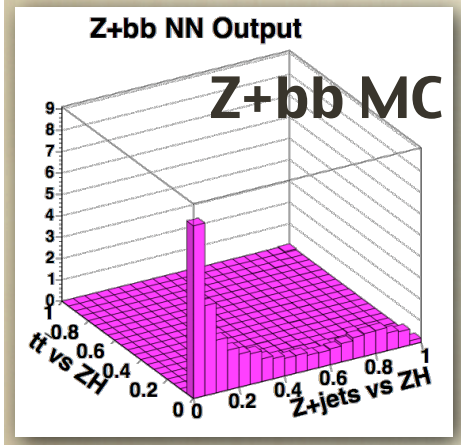


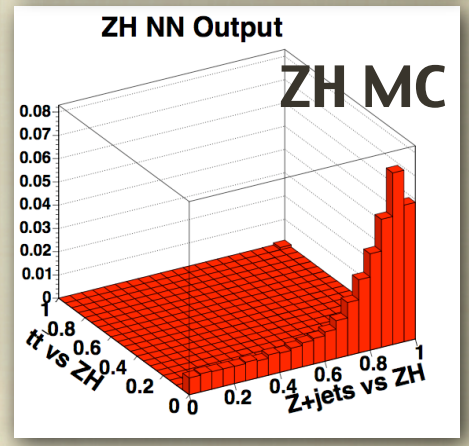
Data: Before b-tagging

Composed of
95% Z+jets





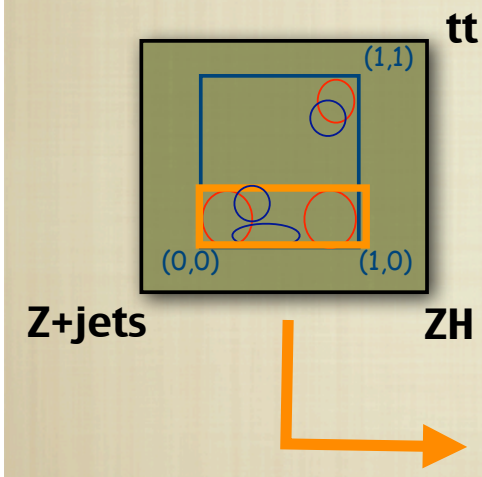


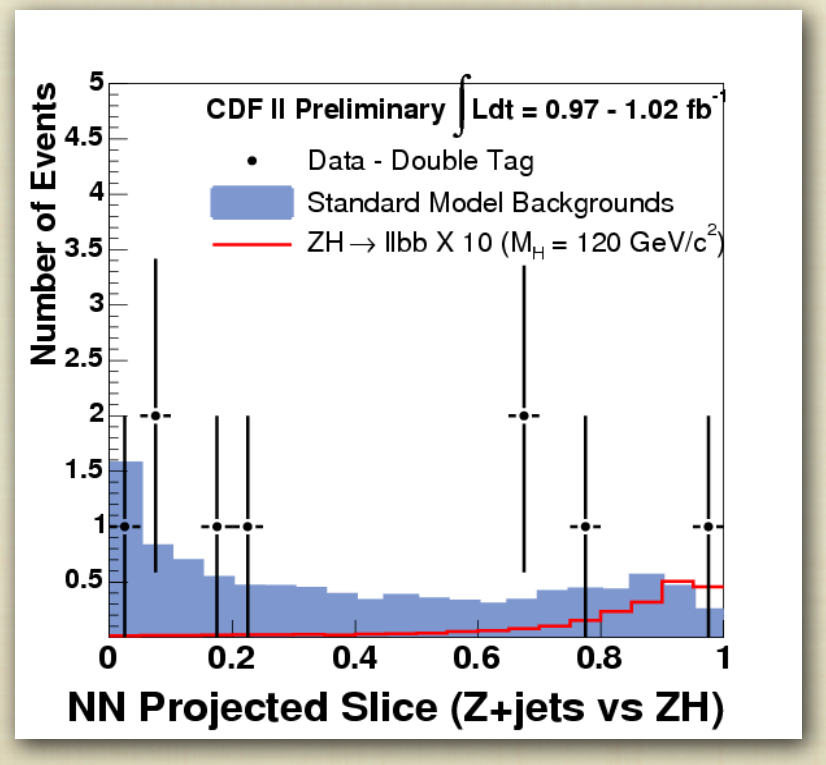


Data : 3000 events
useful for validating NN & background model

One signal region : events with two b-tags

Expected : 12.8 ± 3.5
Data : 11 events





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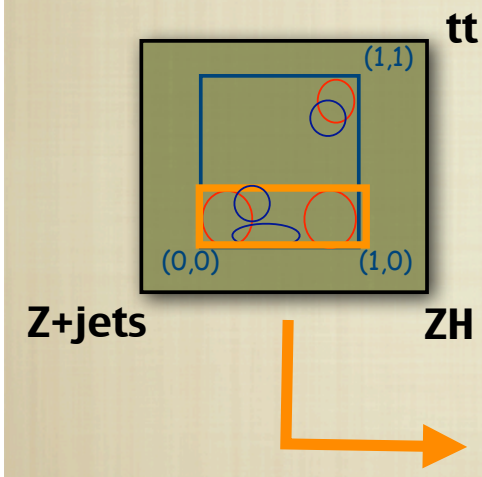
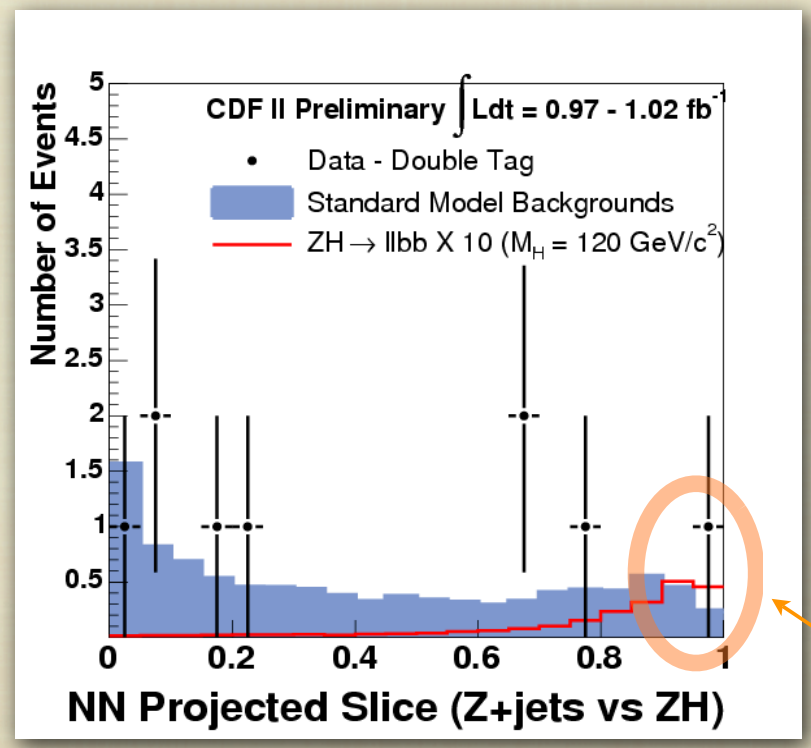




Event in most signal-like bin

Remember, we started with

S:B = 1: 20,000,000,000,000

(BKG stat. uncertainty ~ 2,000,000*SM)

Remember, we started with

S:B = 1: 20,000,000,000,000

(BKG stat. uncertainty ~ 2,000,000*SM)

and we have an event
in most signal-like bin with

S:B = 1:4

Remember, we started with

S:B = 1: 20,000,000,000,000

(BKG stat. uncertainty ~ 2,000,000*SM)

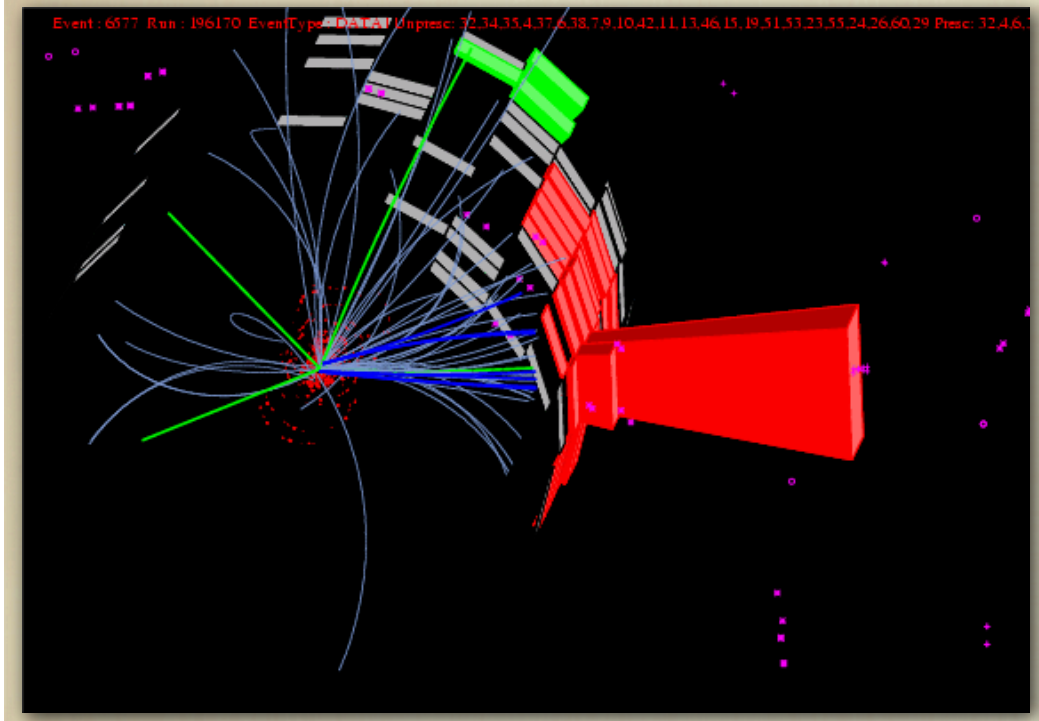
and we have an event
in most signal-like bin with

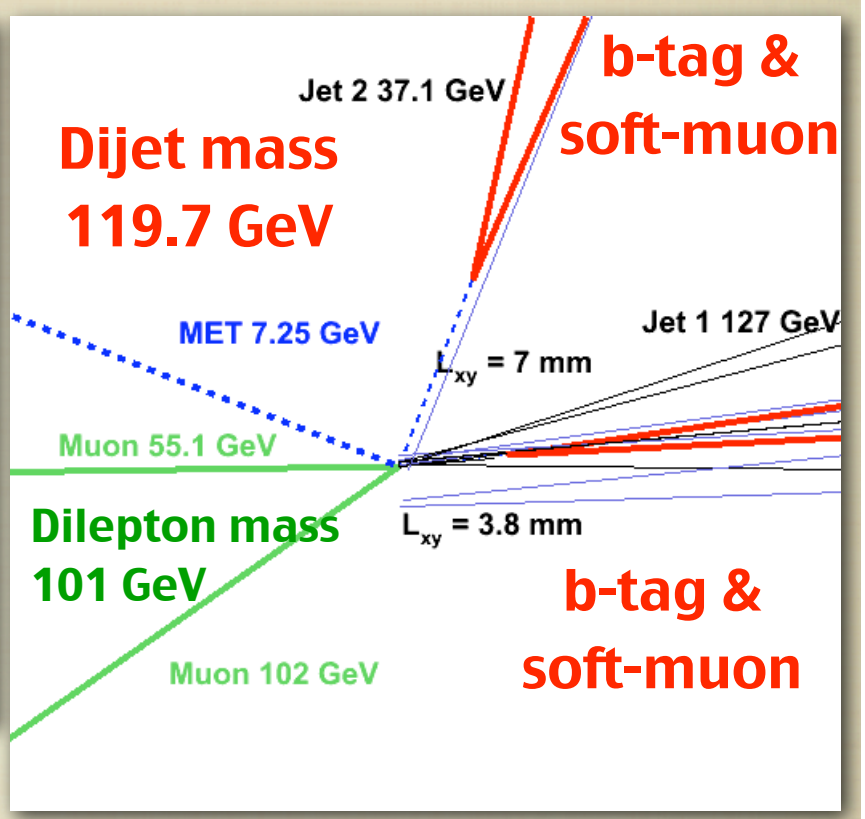
S:B = 1:4

(BKG stat. uncertainty ~ 2*SM)

Higgs candidate S:B = 1:4

RUN 196170 EVENT 6577





Background in this bin

60% Z+bb

11% tt

9% Z+cc

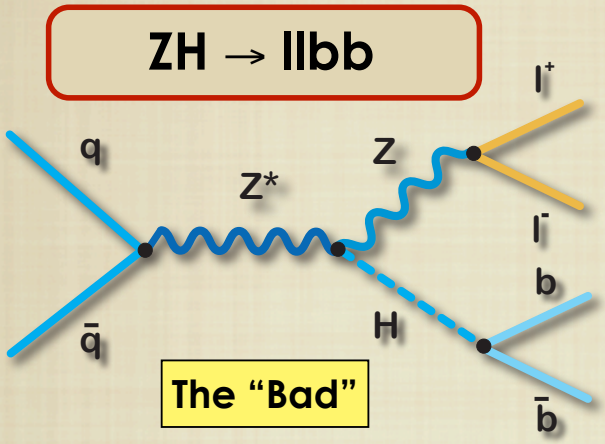
9% ZZ

5% Z+qq (light)

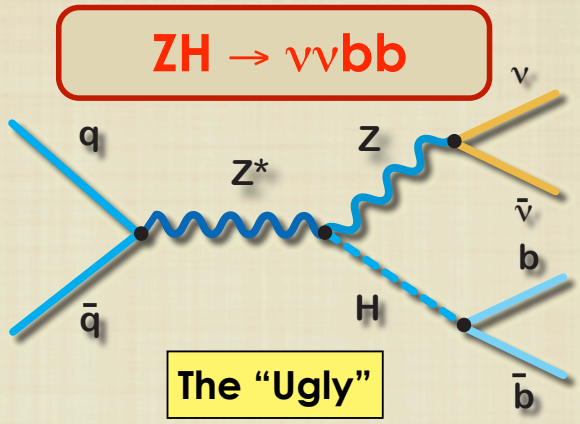
Higgs ~ 2 times tt

$ZH \rightarrow \nu\nu bb$ 3 times larger than $ZH \rightarrow l^+l^- bb$

Can we make similar improvements when $Z \rightarrow \nu\nu$?



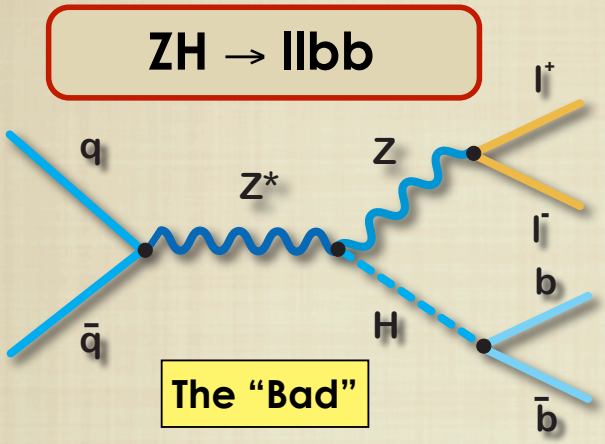
- Fully reconstructed
- Triggered by high quality lepton
- No real Missing E_T
- Mostly Z backgrounds

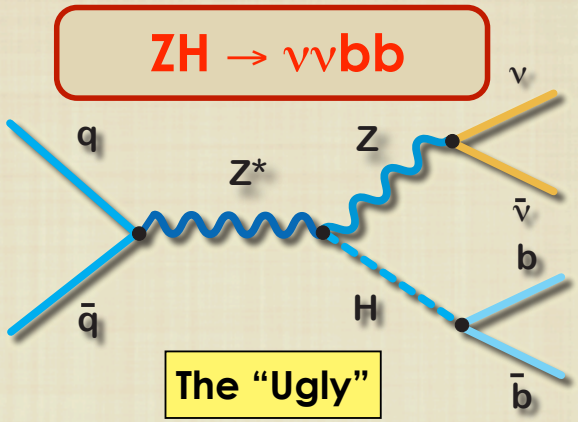


- Partially reconstructed
- Triggered by low quality missing energy
- Real Missing E_T
- QCD is largest background

$ZH \rightarrow \nu\nu bb$ 3 times larger than $ZH \rightarrow l^+l^-bb$

Can we make similar improvements when $Z \rightarrow \nu\nu$?





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- Mostly Z backgrounds

- Partially reconstructed
- Triggered by low quality missing energy
- Real Missing E_T
- QCD is largest background

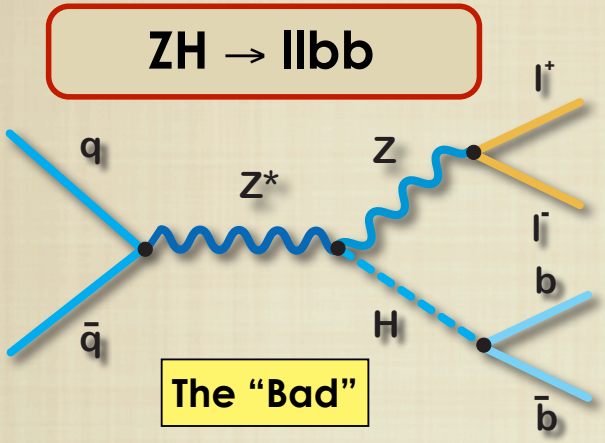
Special techniques :

Dijet + MET fitter

2D Neural Network

ZH →νν̄bb̄ 3 times larger than ZH →l⁺l⁻bb̄

Can we make similar improvements when Z →νν̄ ?



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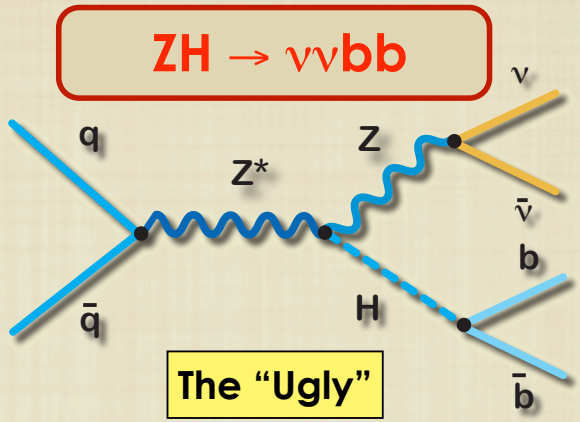
- No real Missing E_T
- Mostly Z backgrounds



- Partially reconstructed
- Triggered by low quality missing energy
- Real Missing E_T
- QCD is largest background

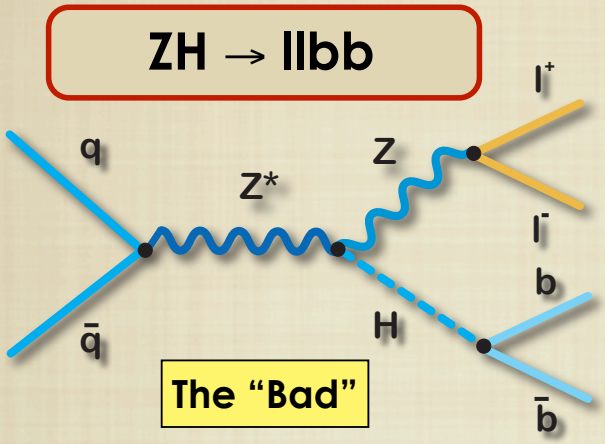
Special techniques :

Dijet + MET fitter

2D Neural Network

$ZH \rightarrow \nu\nu bb$ 3 times larger than $ZH \rightarrow l^+l^- bb$

Can we make similar improvements when $Z \rightarrow \nu\nu$?



- Fully reconstructed
- Triggered by high quality lepton
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Special techniques :
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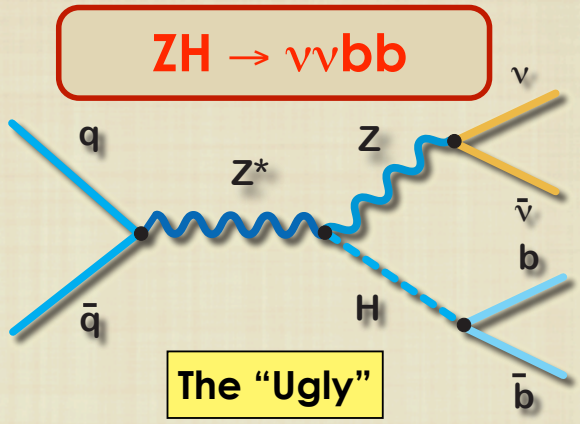

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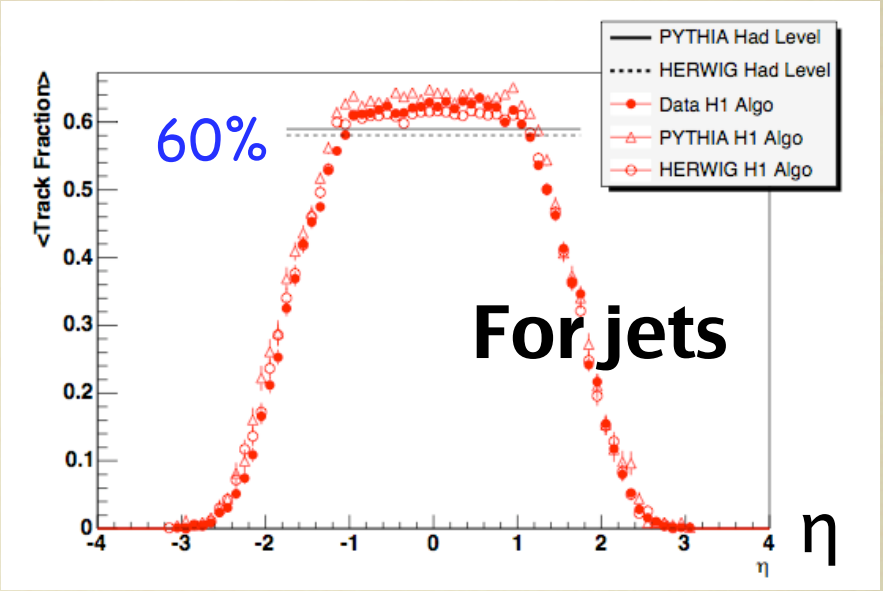
What special techniques for this one ?

Using tracking to reduce QCD

- MET typically measured in calorimeter
- But majority of hadronic energy carried by charge particles
- Track momenta well measured in drift chamber



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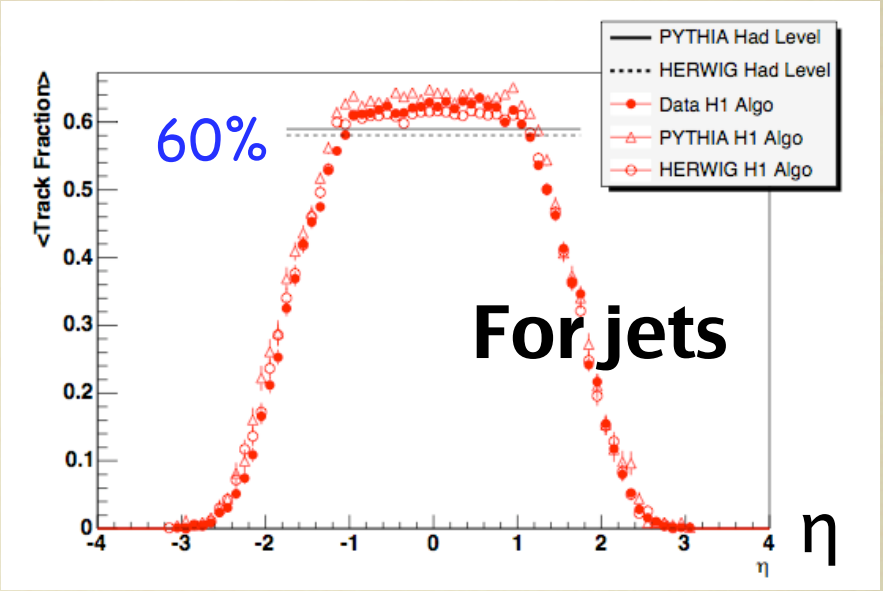

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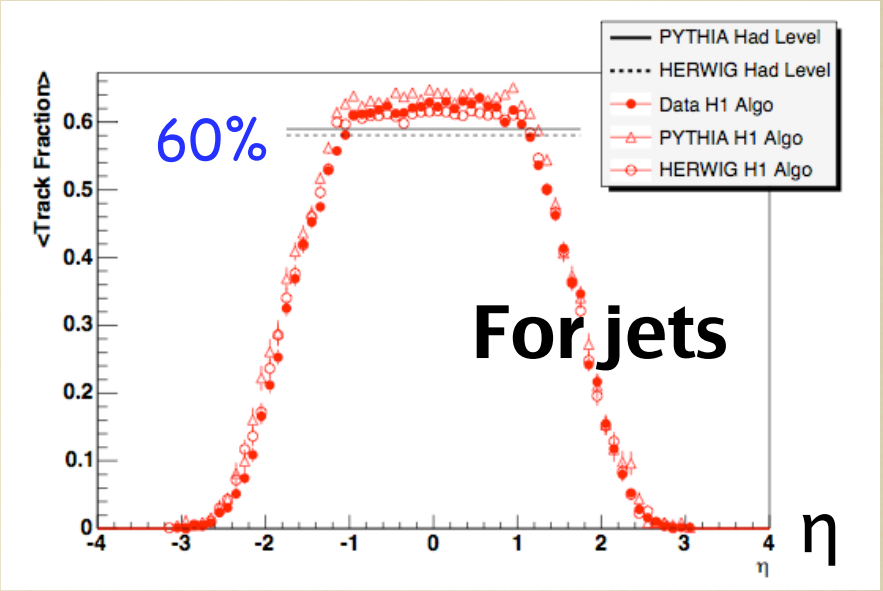
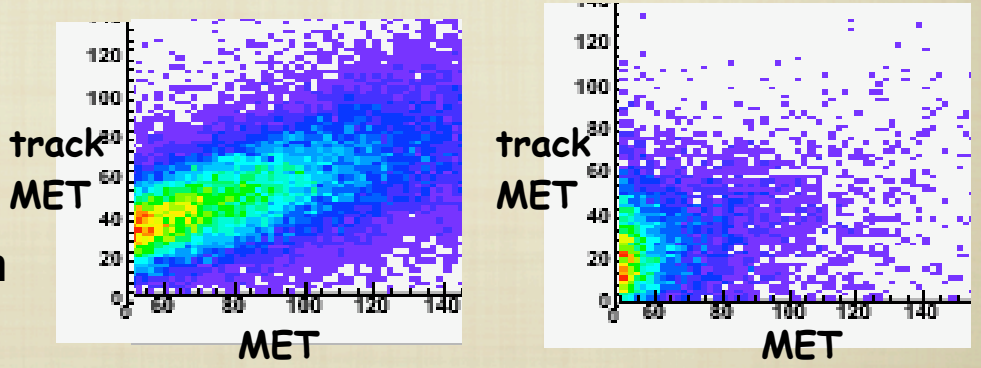


- Can calculate missing track momenta, "trackMET"
- trackMet is correlated to MET when real neutrinos
  - Higgs events
- trackMet uncorrelated to MET when jet is mismeasured in calorimeter
  - QCD multi-jet events

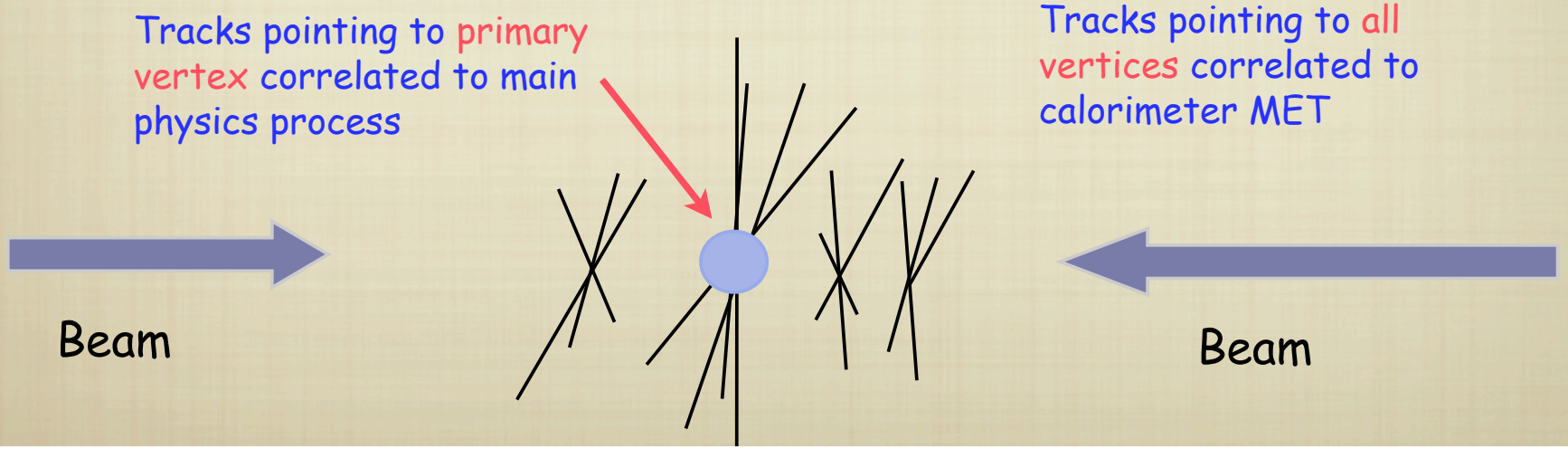


Higgs events

QCD events

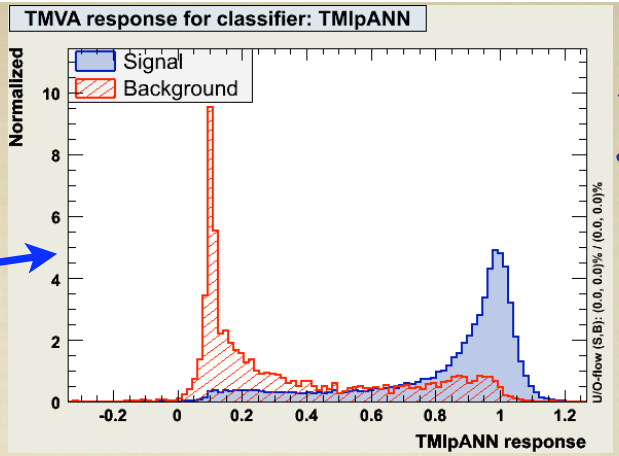
Track-based variables

- Advantages of trackMET
  - Can extrapolate tracks to primary vertex
    - Disentangle MET from additional interactions
    - Independent of instantaneous luminosity (number of vertices)
      - ~7 interactions per crossing at peak 300 E 30 $cm^{-2}s^{-1}$
  - Can remove effects of magnetic field
    - Measure MET at vertex rather than at calorimeter
  - Other variables provide additional signal discrimination :
    - Sum Pt of tracks
    - Maximum Pt of tracks
    - We combine several track-based variables into a discriminant



ZH → νν̄bb̄ discriminants

- Signal to background (QCD) separation using only tracking information



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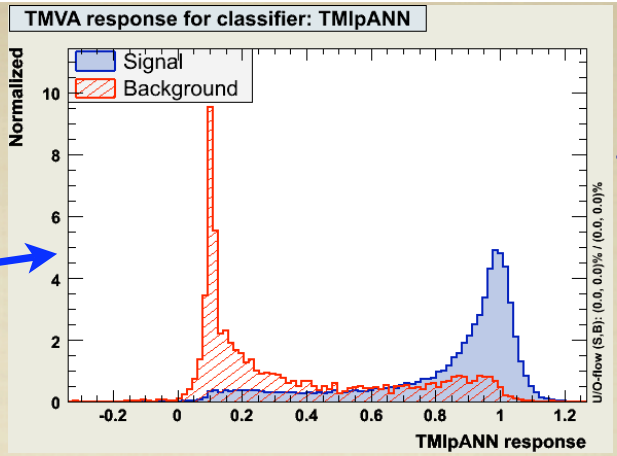

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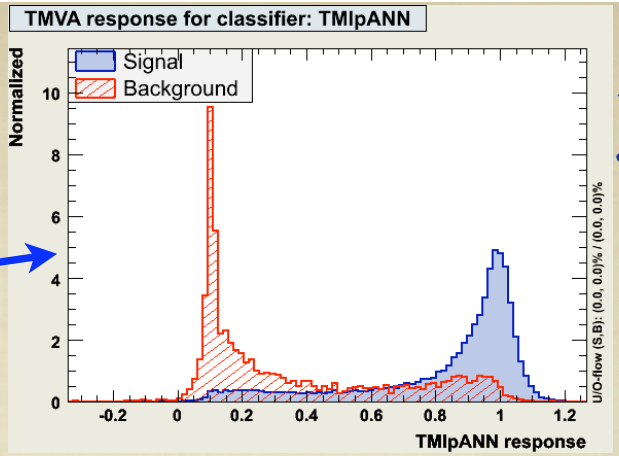

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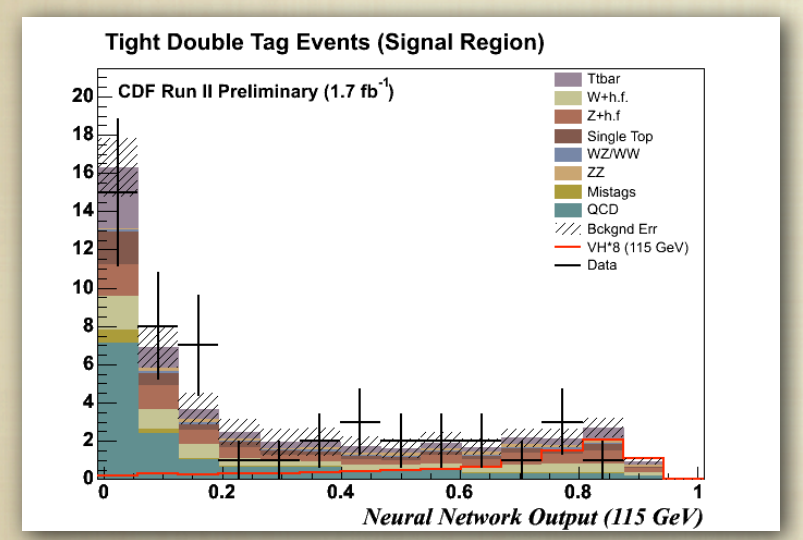

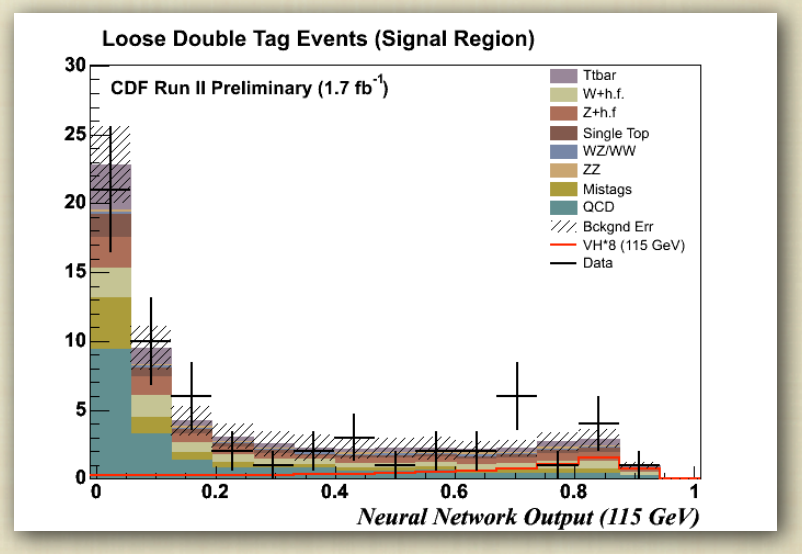

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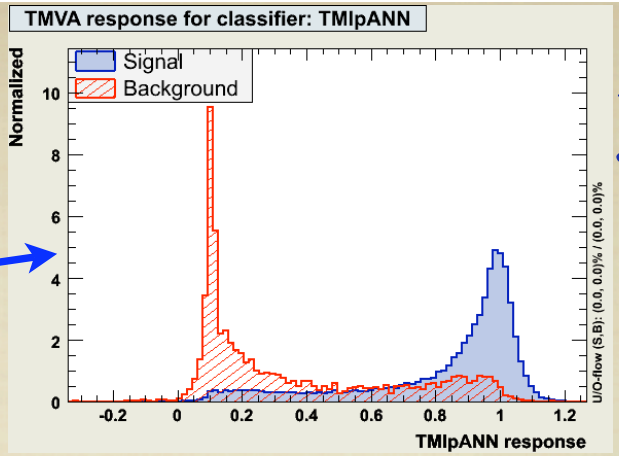

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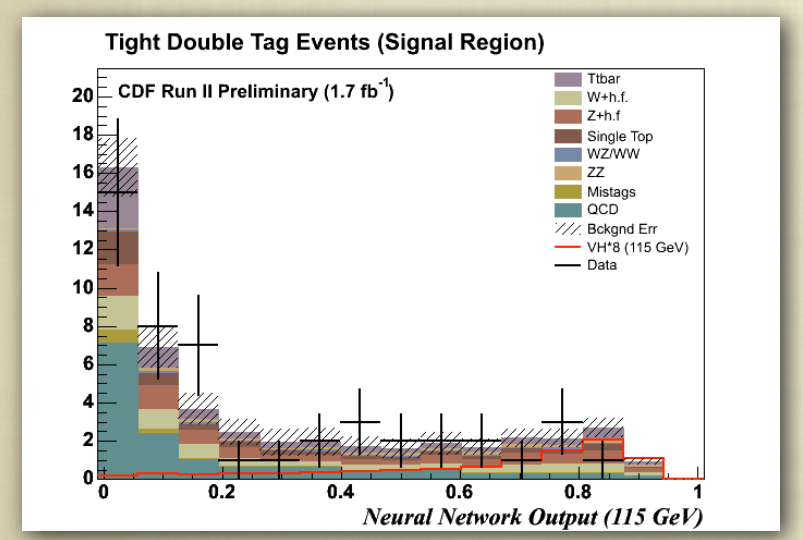

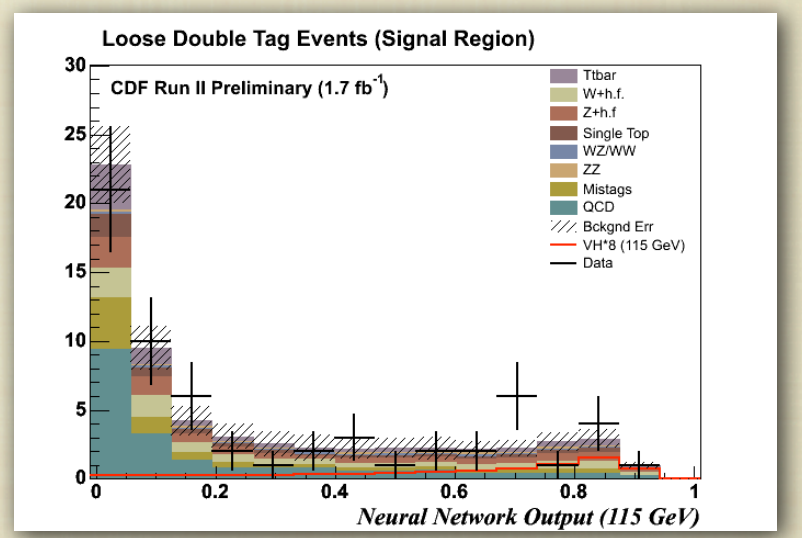

- No signal found, so we set limits
  - For m_H = 115 GeV, 1.7 fb^{-1}
    - Observed limit is 8.0 * SM Higgs cross-section
    - Expected limit is 8.3 * SM Higgs cross-section

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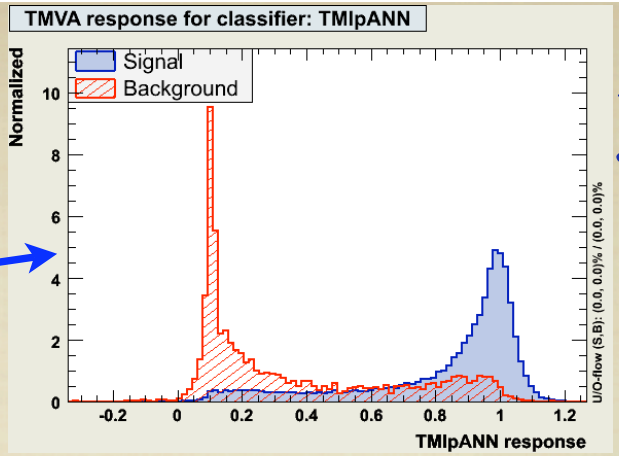

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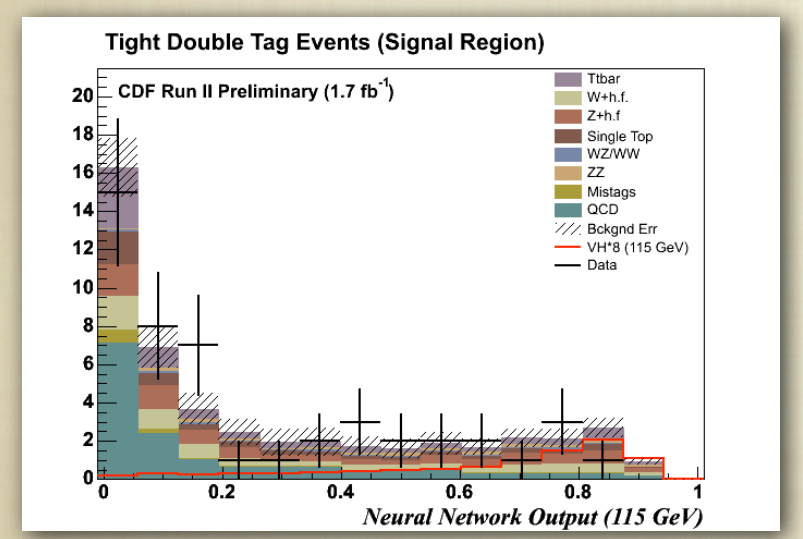

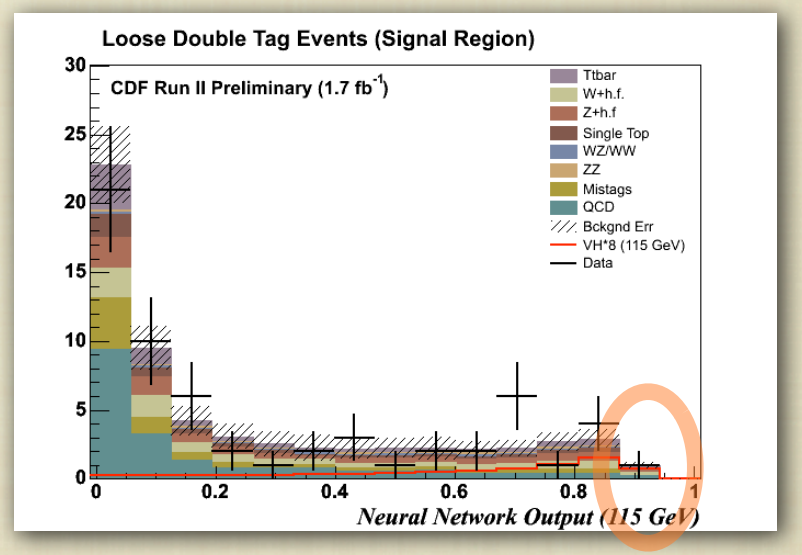

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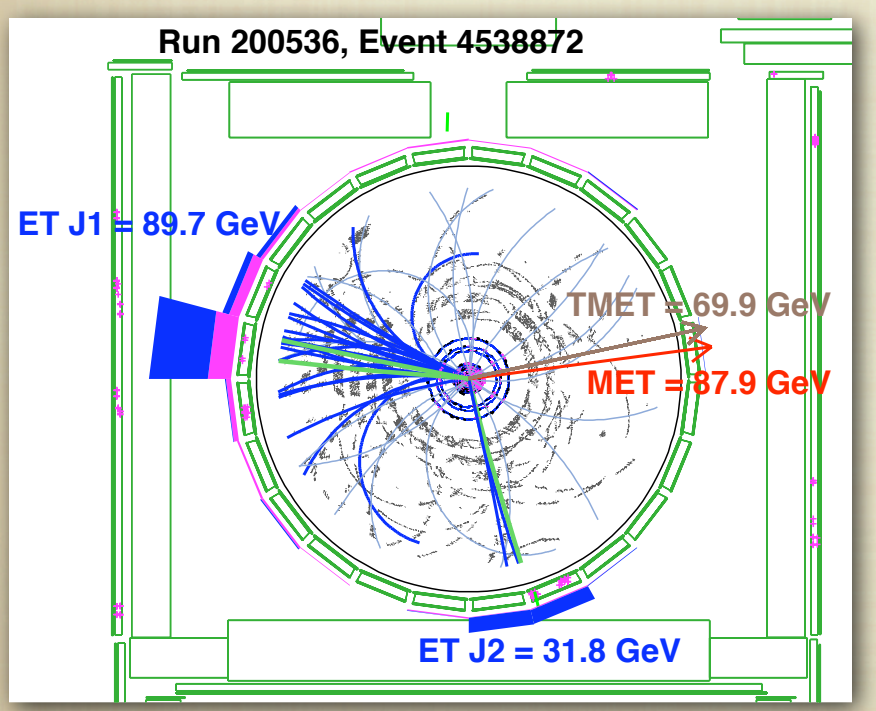
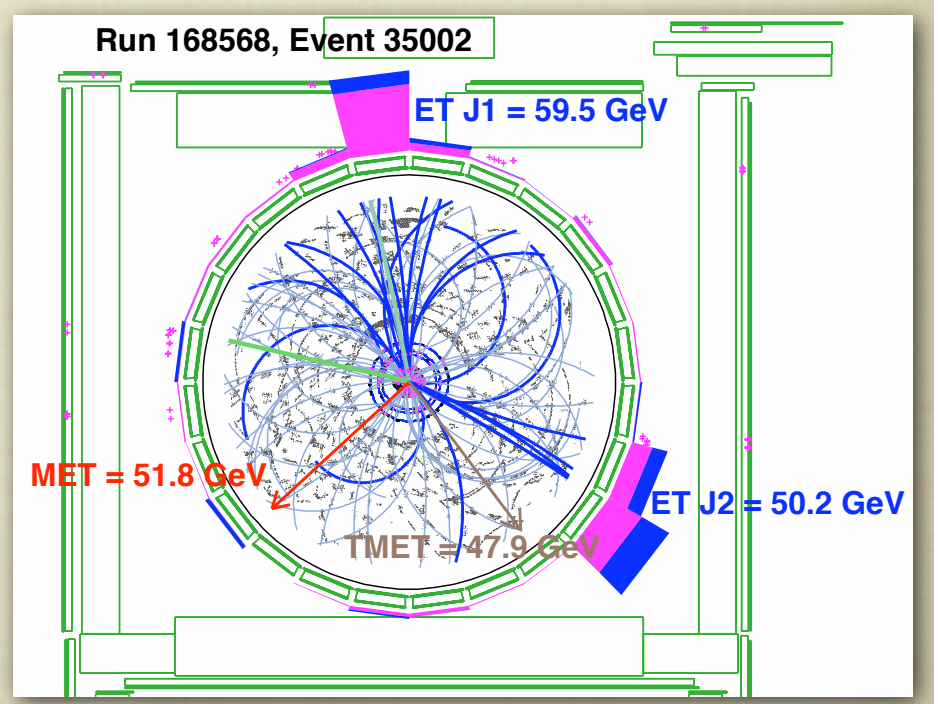
Most signal- like event

$ZH \rightarrow \nu\nu bb$ candidates in Data

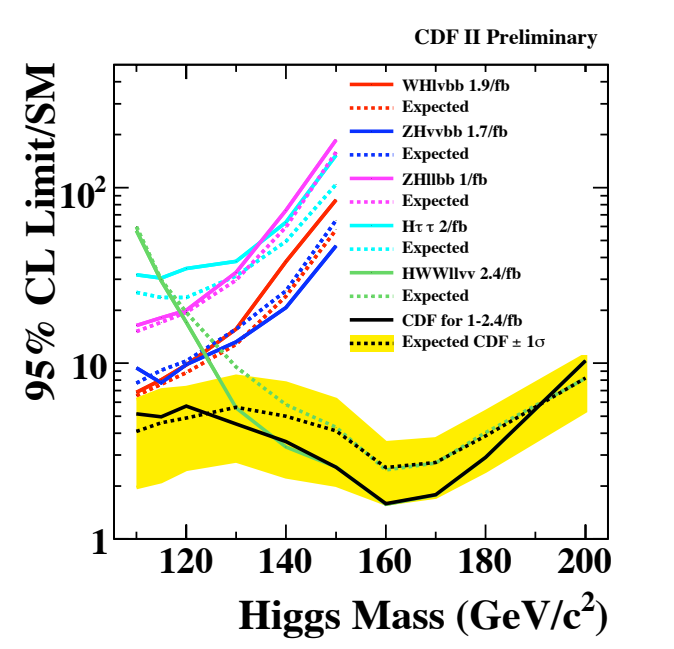
- **Most Higgs-like event**
  - M_{jj}= 113 GeV
  - Track MET points toward MET
    - indicates real neutrinos
    - High NN Output (0.89)



- **QCD-like event**
  - M_{jj}= 156 GeV
  - Track MET points toward jet
    - indicates mismeasured jet
      - Low NN Output (0.003)



Combining multiple channels



- CDF alone has 5 Higgs channels divided into 10 separate search channels to improved Sig vs. Bkg.

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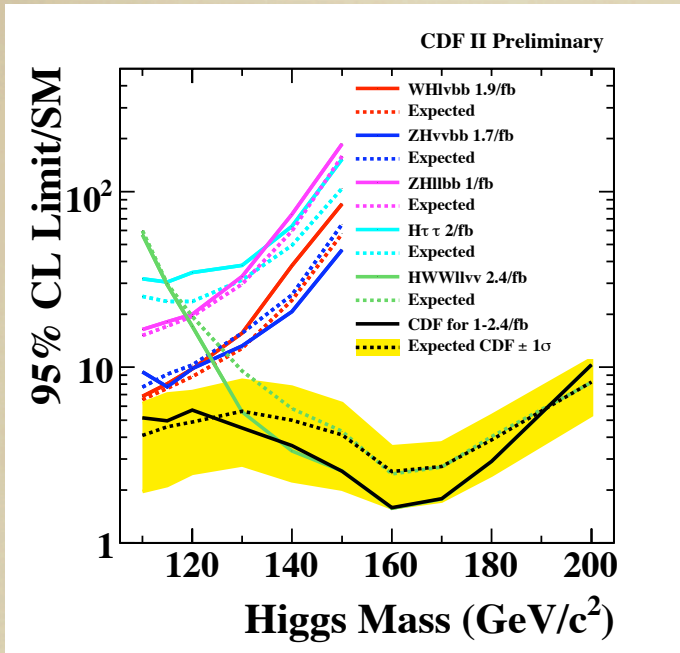

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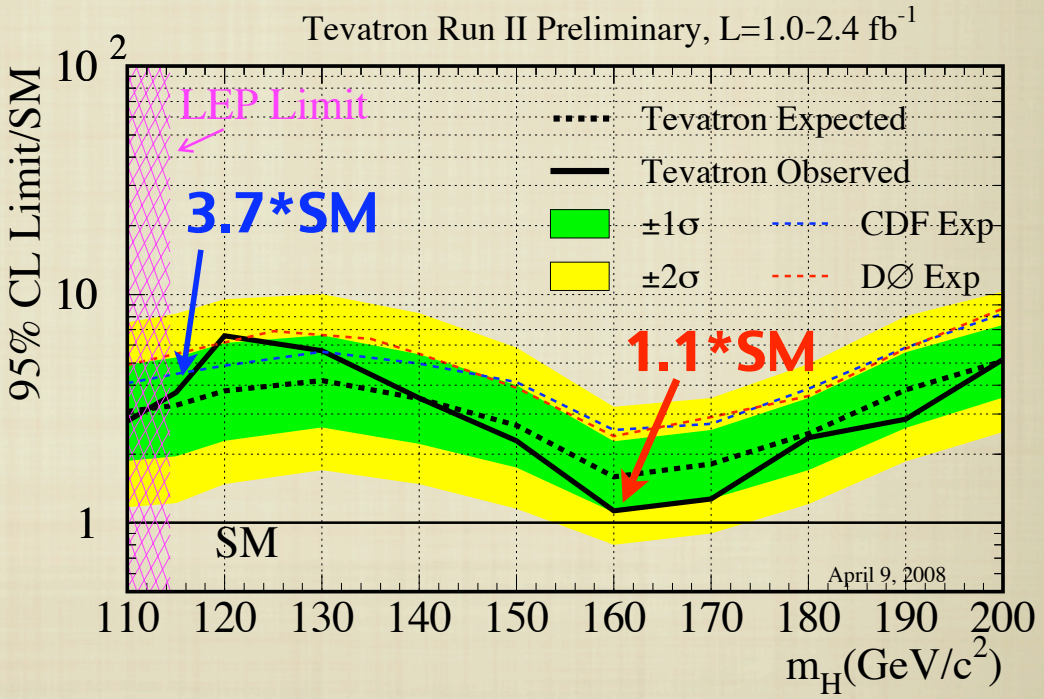

- CDF and D0 together have about 20 such search channels

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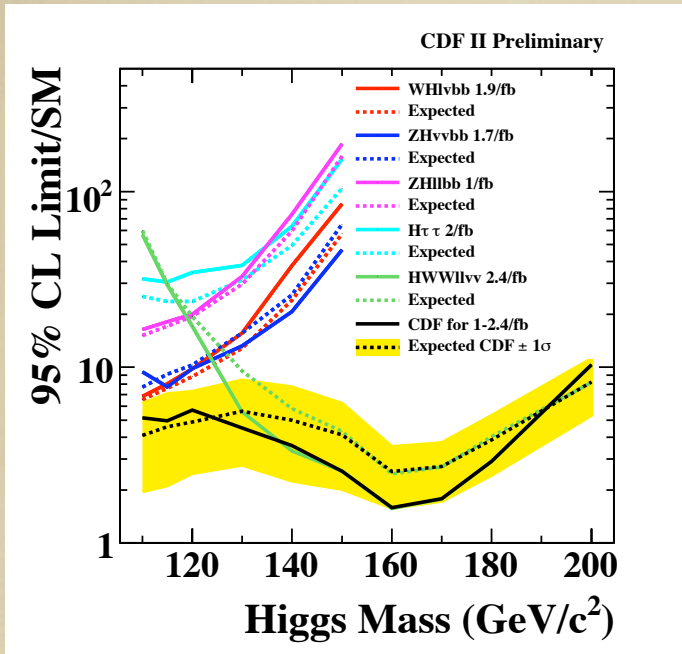

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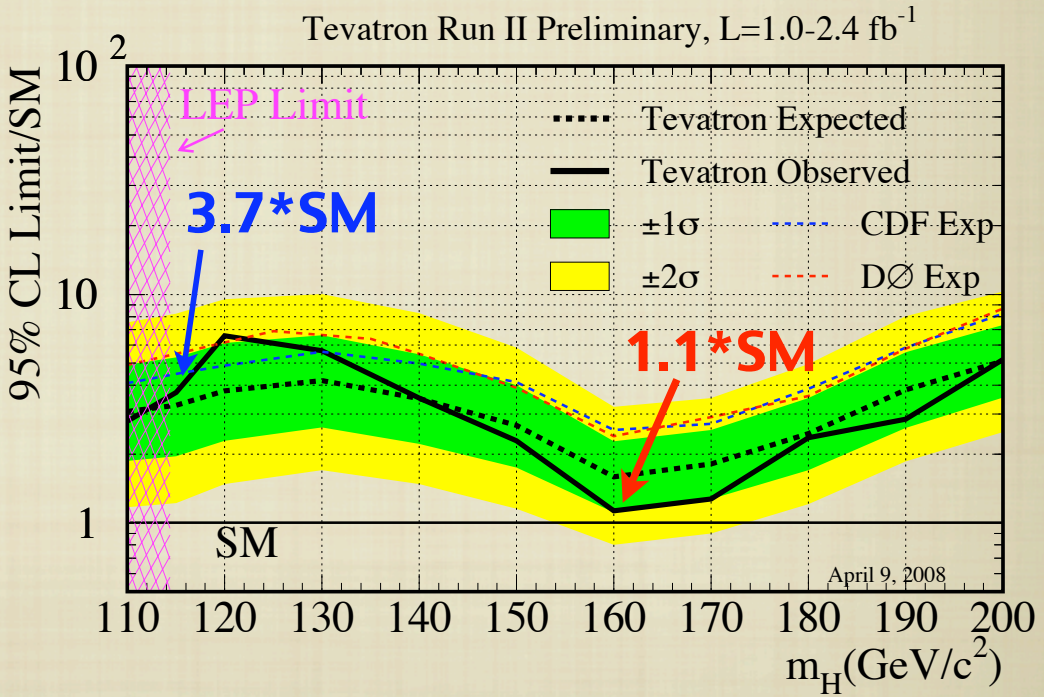
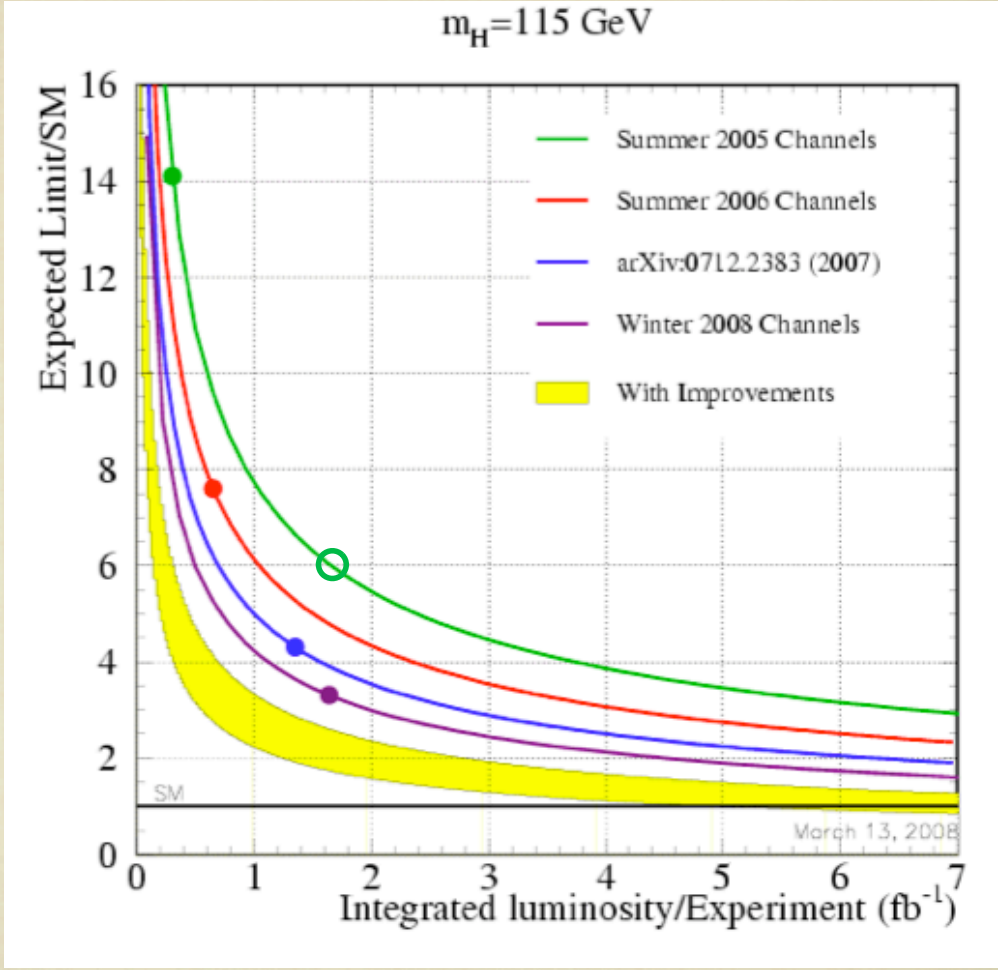


- CDF and D0 together have about 20 such search channels

- Indirect constraints expect $m_H < 160$ GeV/c² @ 95% CL
- We will soon be able to exclude $m_H \sim 160$ GeV/c²

Why it is worth doing Higgs

- Analyses are getting better
  - We've had ideas
  - We still have ideas
  - Data still coming



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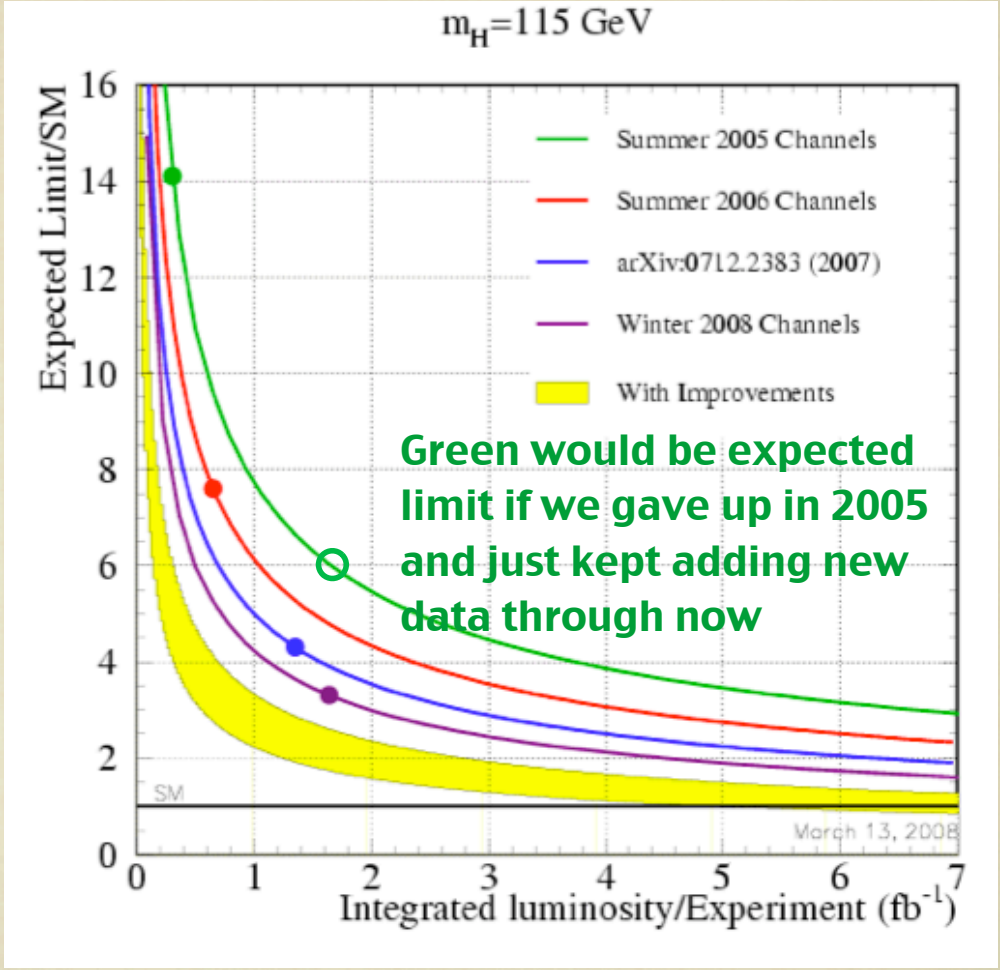

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Expected limit goes down ↓

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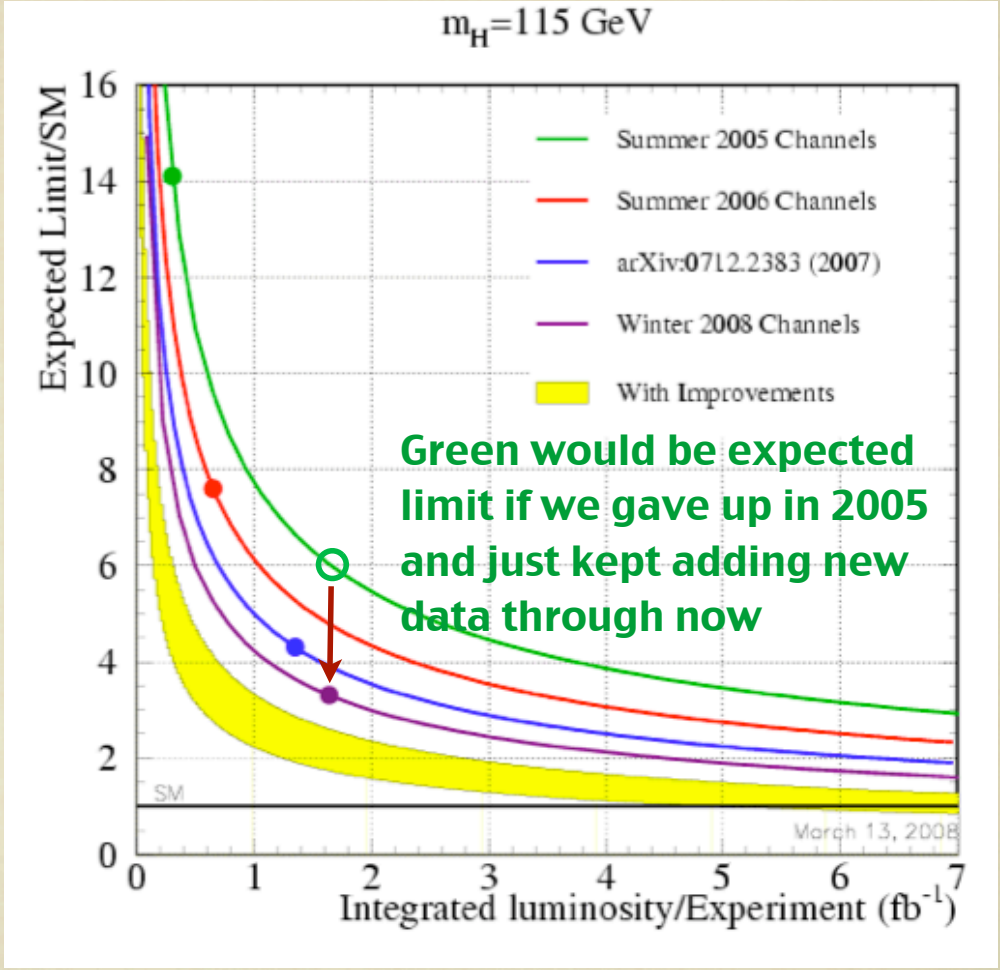
Creativity + Perseverance go up ↑



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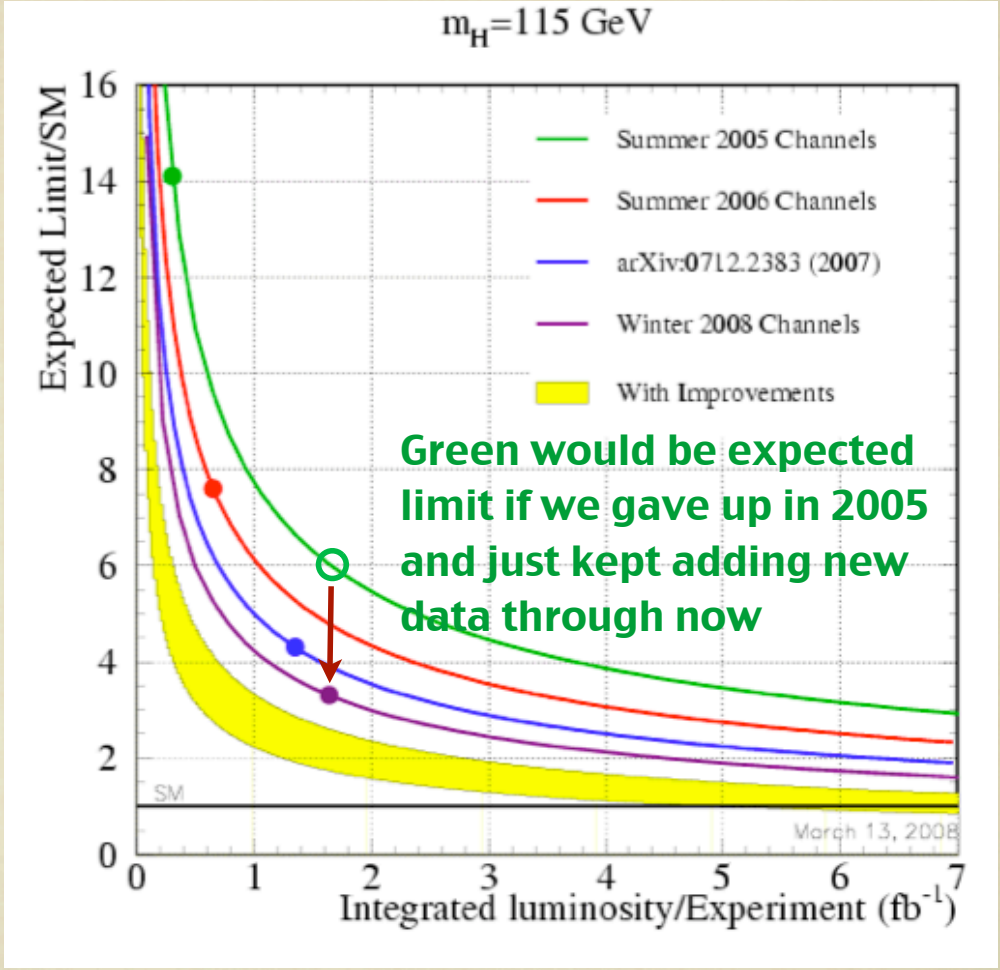

Advertisement : Got an idea ? Maximize your impact by having it here !

Conclusions

- Two CDF searches for Higgs in ZH make good
  - $Z \to ll + H \to bb$: the "Bad"
    - Reduced background by improving dijet mass resolution
    - Used 2-D Neural Network to distinguish Higgs signal
    - Most sensitive channel with 1 fb^{-1}
  - $Z \to \nu\nu + H \to bb$: the "Ugly"
    - Reduced background by using track-based variables
    - Used Neural Network to distinguish Higgs signal
    - Most sensitive channel with 1.7 fb^{-1}
- Tevatron Higgs program is still in the race
- Lessons from these searches can be applied to LHC

Expect > 3 times more data

Improvements in analysis technique are ongoing

Tevatron duel for the Higgs getting more exciting

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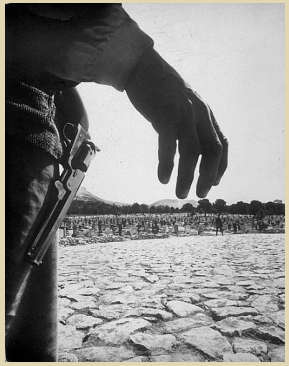

A special acknowledgment

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- Ohio State U. grad student
- Thesis analysis: ZH →νν**bb**
- Status: writing up PhD thesis

Jonathan Efron

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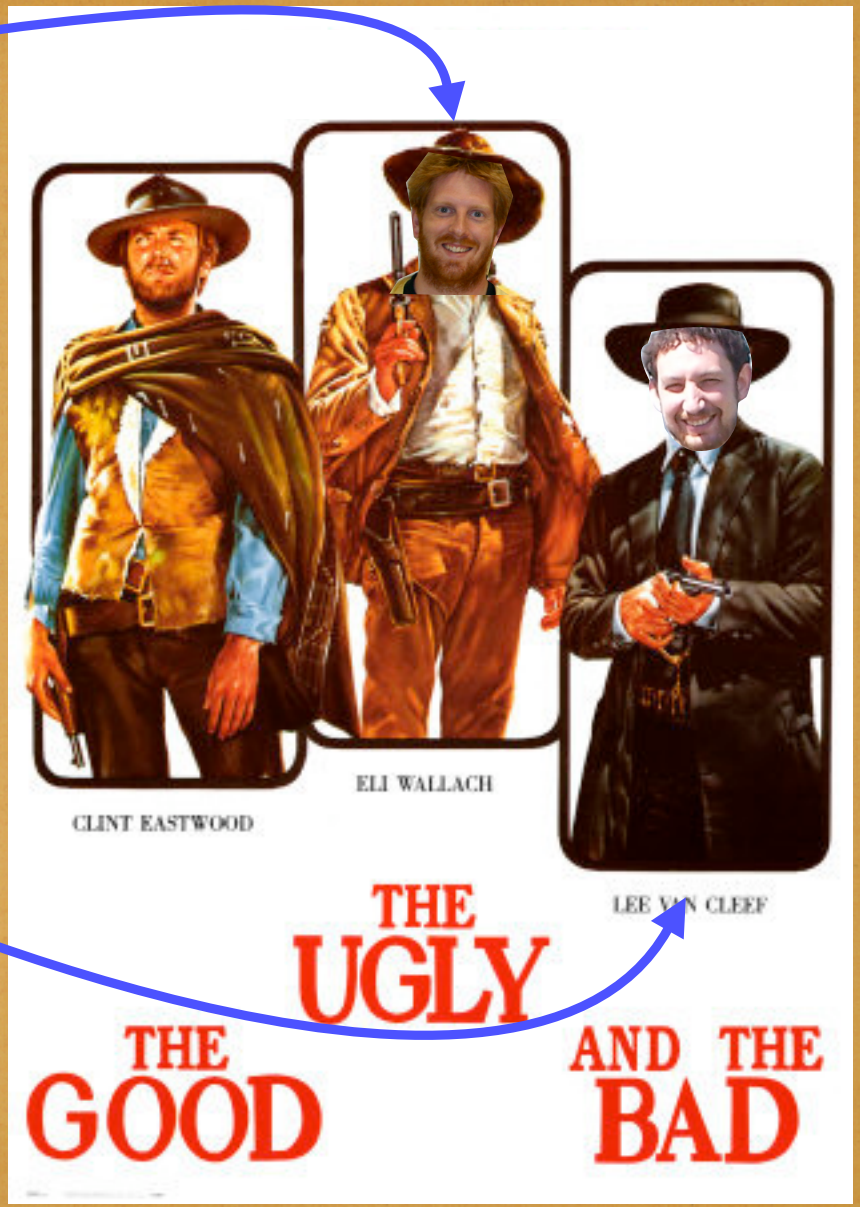

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No offense guys …